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## Evaluation of Soil Type and Seeding Rate on Winter Cover Crop Species in a Soybean Production System

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**EVALUATION OF SOIL TYPE AND SEEDING RATE ON  
WINTER COVER CROP SPECIES  
IN A  
SOYBEAN PRODUCTION SYSTEM**

A Dissertation

Submitted to the Graduate Faculty  
of the Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Doctor of Philosophy

in

The School of Plant, Environmental Management, and Soil Sciences

by

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## ABSTRACT

The integration of winter annual cover crops into a cropping system can potentially improve soil health and crop production, however, the impact of variables such as seeding rates, across two very different soil types, has not been well documented. A two-year study was conducted at the Dean Lee Research Station and Extension Center in Alexandria, Louisiana to evaluate the effects of cover crop seeding rate and soil type on cover crop biomass, weed suppression, soil fertility, and soybean (*Glycine max* L) growth and yield. Analysis of potential economic impacts was also performed to estimate financial net returns for three broadcast seeding rates of tillage radish (*Raphanus sativus* var. L), cereal rye (*Secale cereale*), and crimson clover (*Trifolium incarnatum*). Low seeding rates of tillage radish produced greater biomass than high rates (1,812 and 807 kg ha<sup>-1</sup>, respectively) but did not significantly affect cereal rye or crimson clover. Weed biomass for all seeding rates of cereal rye and low and medium rates of tillage radish was lower (ranging from 18-323 kg ha<sup>-1</sup>) compared with all seeding rates of crimson clover. Nutrient levels for macro and specific micro-nutrients fluctuated with sample date and soil type, but overall, levels were lowered by 7-88% over the course of this study. Soil organic matter levels were significantly different by sample date across years and soil types, but overall levels decreased from 2.5% to 1.9%. Soybean yield was different by soil type and year, with Coushatta silt loam plots yielding 41% higher than Moreland clay (3,504 and 2,079 kg ha<sup>-1</sup>, respectively). Although production year 2017 (3,434 kg ha<sup>-1</sup>) yielded 39% greater than 2018 (2,147 kg ha<sup>-1</sup>), cover crop seeding rate had no impact on soybean yield in this study. Economic estimations were calculated based on cover crop inputs and soybean grain yield with high rates of tillage radish and cereal rye being less profitable compared with a fallow treatment (all other species and seeding rates were equal to fallow) for Coushatta silt loam soil. In contrast, all rates

and species were equal to fallow in Moreland clay except for low rate of cereal rye. Under specific conditions and soil type, low and medium cover crop seeding rates may provide adequate biomass and weed suppression without sacrificing biomass or net monetary returns.

# **CHAPTER 1. INTRODUCTION**

## **1.1. Evaluation of Healthy Soils**

With an expanding global populations expected to reach 9.5 billion people by 2050, tremendous pressure on agricultural land and resources make soil health and sustainability a critical part of modern-day agriculture (Reicosky, 2015). By definition, soil health is the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health (Doran and Zeiss, 2000). For agricultural soils to be considered sustainable, crop yields would need to be maintained or improved without compromising environmental integrity or the future in terms of resource degradation or public health (Tilman et al., 2002; Matson et al., 1997).

Although there are currently no scientific criteria to evaluate the sustainability of a specific farming system (Stockle et al., 2009), measurements can be made through continuous evaluation of soil health and of independent indicators of chemical, physical, and biological soil properties (Rattan and Lal, 1998; Doran and Jones, 1996; Van-Camp et al., 2004). These may help determine if the soil is able to sustainably produce crops, or if management practices should be modified to maximize the soil's potential. Different land uses may require increased capacities for specific soil functions, which may use certain indicators over others for assessment. Soil quality is the inherent attribute of a soil that is inferred from its specific characteristics and observations like compaction, erodibility, fertility, and structural integrity (Parr et al., 2002). Though soil quality cannot be measured directly, these independent indicators can be used to assess the change in soil function within land use or ecosystem boundaries (Seybold et al., 1998). A multitude of studies have shown that encompassing all three soil



properties are beneficial in soil quality assessment (Larson and Pierce, 1991), however, one of the more common and easily accessible methods is through chemical evaluation. This includes measuring soil pH, cation exchange capacity (CEC), macro and micro-nutrients, soil organic matter (SOM), and inorganic nitrogen (N) (nitrate,  $\text{NO}_3^-$ -N and ammonium,  $\text{NH}_4^+$ -N). In contrast, physical quality indicators are mainly concerned with soil texture, moisture-holding capacity, bulk density, porosity, aggregate strength and stability, crusting, surface sealing, compaction, and depth (Pathak et al., 2005). No single measurement can quantify soil health, but certain bio-physical and chemical characteristics are found to be key potential indicators (Nambiar et al., 2001). Visual assessment and crop yield are also used in conjunction with other evaluation tools.

Tillage, traffic, plant cover systems, and organic and inorganic inputs (accidental or deliberate) strongly influence all components of soil quality and, thus, ecological functioning (Doran and Parkin, 1996; Guérif et al., 2001). The standard agricultural chemical soil test focuses on a limited number of soil chemical indicators that are critical to crop nutrition but are widely used and relatively easy to obtain with minimal sampling and analysis costs (Schindelbeck et al., 2008).

Many studies now focus on the addition of biological factors to assess soil health. An international study in 2002 found that different microorganisms play a key role in ecologically important biogeochemical processes and parameters such as  $\text{N}_2$ -fixing bacteria, total microbial biomass, and soil respiration and could serve as sensitive indicators of soil quality (Filip, 2002). Because soils are considered an extremely complex living system (Reicosky, 2015), many tools are needed in order to accurately assess the health of the soil, so that measures may be taken to improve or increase soil productivity. Studies have shown that utilizing cover crops is one way to

improve soil productivity by promoting pest-suppression, soil and water quality, nutrient cycling efficiency, and cash crop productivity (Snapp et al., 2005).

## **1.2. Cover Crops and Their Functions**

One principal function of cover crops is to prevent land degradation by wind and water erosion (Langdale et al., 1991) by covering the soil with living vegetation and roots that hold on to the soil (Magdoff and Van Es, 2009). Integrating a vegetative cover into a crop production system may not only reduce soil erosion, but increase cash crop yield, suppress weeds, and improve physical and chemical soil properties (Magdoff and Van Es, 2009). Depending on the geographic location, a typical summer cash crop operation in the southeastern U.S. will utilize the soil for approximately four to five months (planting to harvest) but may leave seedbeds fallow and exposed to the elements during the rest of the year. During this period, bare soil is lost through erosion, microbial activity is reduced due to residue decomposition, and  $\text{NO}_3^-$ -N is subject to leaching in soils where vegetation is minimal (Hoorman et al., 2009). To help mitigate these negative effects, winter covers can provide substantial vegetative and root biomass to reduce erosion and runoff, improve nutrient availability, and increase microbial diversity and activity for nutrient cycling (Clark, 2007).

Though there has been substantial overall research on both winter and summer annual cover crops, limited information is available for winter covers in the southern and southeastern U.S. (Snapp et al., 2005). Cover crop species are currently selected for specific geographic regions of the country based on cold-tolerance and environmental adaptability (Magdoff and Van Es, 2009). Variability in cover crop species, which may include optimum planting dates, seeding depths, drought tolerance, and biomass potential, would require modifications to management in different climates across the country. Typical, above freezing, winter weather in the southeastern

U.S. provides a suitable habitat for pests to over winter and weeds to flourish, making winter cover crop management in that environment a challenge.

### **1.2.1 Cover Crop Species**

One of the most critical management decisions when planting cover crops is selecting a species that will establish easily, produce significant biomass in a relatively short time-period, and terminate easily when preparing for the following crop. Species selection may be significantly influenced by timing of cash crop planting and harvest but identifying field objectives such as reducing soil erosion, adding a N source, suppressing pests, or enhancing yields (Snapp et al., 2005) is critical as well. In addition, seed availability and cost may also be a factor.

Cover crops can generally be categorized into three species: legumes, grasses, and brassicas. Legume cover crops, which would include winter annuals such as crimson clover (*Trifolium incarnatum*), hairy vetch (*Vicia villosa*), and Austrian winter pea (*Pisum sativum* subsp. *arvense*), can provide additional soil N to crops through N fixation, while grasses and brassicas help scavenge existing N while reducing erosion and suppressing weeds (Ebelhar et al., 1984). While dependent on microbial, soil, and environmental variables, leguminous plants have the ability to fix atmospheric N<sub>2</sub>, through a symbiotic relationship with rhizobia bacteria, and provide a nutrient source to the following crop (Peoples et al., 2009). Clover and hairy vetch residue have a more rapid decomposition rate than other cover crops due to its low C:N ratio (Fageria et al., 2005), which allows microbial populations to break down the residue to use as an energy source, while releasing plant-available N. This N can provide up to 167-179 kg N ha<sup>-1</sup> for the following crop, thereby decreasing the amount of additional N fertilizer that would need to be applied (Crozier et al., 2014). Legumes can also scavenge residual soil N before fixing their own,

but because of slower establishment, they are not normally planted for the primary purpose of scavenging (Kladivko, 2016). Soybeans (*Glycine max* L.), a summer annual cash crop and legume, can also be used as a cover crop during the fallow period in crops such as sugarcane (*Saccharum officinarum*) production systems to improve soil health and can supply excess N to the soil N “bank” (Park et al., 2010).

Non-legume cover crops, which include grasses, will scavenge or “trap”  $\text{NO}_3^-$ -N that would otherwise move out of the root zone into groundwater or away from the plant. Common cover crop grasses include annual cereals such as cereal rye (*Secale cereal*), wheat (*Triticum*), barley (*Hordeum vulgare*) and oats (*Avena sativa*). Typical wet, winter fallow periods between crop maturity and establishment of the next crop give adequate time for soil N to “leak” when there is nothing to actively take up the N (Kladivko, 2015), especially in soils where leaching is an issue. Scavengers tend to have extensive root systems and can help limit the loss of N to the environment (Delgado, 1998; Delgado, 2001; Delgado et al., 2001a; Delgado et al., 2001b). In a Michigan field crop study, Kinyangi et al. (2001) found a reduction in  $\text{NO}_3^-$ -N leaching losses was possible through planting winter rye cover but only occurred when extra N fertilizer was not applied when planting the cover crop. Fall planted cover crops use residual  $\text{NO}_3^-$ -N thereby reducing its loss from the soil (Power and Doran, 1988).

Brassicas may include mustard (*Brassica rapa* var. *rapa*), rapeseed (*Brassica napus* var. *napus*), and forage or oilseed radishes (*Raphanus sativus* L.). These crops are fall-planted and can be used to scavenge N left in the soil by the previous crop and absorb up to 112-168 kg N  $\text{ha}^{-1}$  (Weil and Williams, 2003). Oilseed radishes have a thick taproot that can penetrate compacted soil layers and decomposes in the spring, leaving large, deep holes. These holes allow for better gas exchange, nutrient cycling, and penetration of primary taproots into the soil

structure more easily. The radish's deep tap roots allow  $\text{NO}_3^-$ -N absorption at greater depths, preventing it from leaching into groundwater (Jacobs, 2012). A study conducted in 2004 showed soybean roots growing through compacted plow-pan soil using the channels made by decomposing cover crop roots, and increased yield where drought and compaction were the greatest (Williams and Weil, 2004). Regardless of species, when managed properly, cover crops can also improve production and increase the yield of the following cash crop (Kambauwa et al., 2015).

### **1.2.2 Managing Cover Crops**

Cover crop management in a no-tillage system prior to planting a principal crop can be an important tool in maximizing the benefits of the cover crop on the principal crop (Wagger, 1989). Optimum planting date, termination date, and residue management decisions must be made prior to implementation to maximize cover crop biomass. Most winter cover crops have a wide range of recommended planting dates from late summer to late fall, depending on region and intended use. Although it is generally recommended that cover crops be planted six to eight weeks before the average first frost date (Clark, 2007), some research has shown that planting dates within winter grass species have no effect on biomass accumulation (Bauer and Reeves, 1999). Brennan and Smith (2017) also reported that in an evaluation of termination dates for oats (*Avena sativa*), a mustard (*Brassica*), and a legume (*Fabaceae*)/oats mixture, there were no differences in biomass accumulation by termination. This may be accurate in some situations, however, if a particular cover crop is winter-killed, such as tillage or oilseed radish, planting early in the fall may be critical in biomass accumulation before the temperatures fall below  $-5\text{ }^\circ\text{C}$  for several nights in a row (Clark, 2007).

When and how to terminate a winter cover crop affects cover crop N and availability to subsequent crops. Cash crop planting dates and field conditions will typically dictate the timing of cover crop termination, so that biomass and residue will have sufficient time to decompose and release N when it is needed. Crimson clover is easily terminated by mowing or spraying with a non-selective herbicide in the early growth stages, but N gains are increased by waiting until late bloom or early seed set (Clark, 2007). One study that evaluated three cover crop planting and termination dates reported that biomass and N content increased for each delay in termination date (from late March until early May). That research also indicated that a hairy vetch-cereal rye mixture had equal or greater N than vetch alone (144-203 kg ha<sup>-1</sup>), and greater N than cereal rye (51 kg ha<sup>-1</sup>) within each termination date (Clark et al., 1997). Some cover crops are mechanically rolled, crimped, or chemically terminated on the day of cash crop planting to maximize growing days and N accumulation. This is referred to as “planting green”, and can be risky due to possible pest carryover, soil moisture issues, and competition until the cover crop completely dies (Gillespie, 2019).

How the cover crop residue is managed once it is terminated will help determine decomposition rate. The amount of N that will be effectively be used by the succeeding crop will depend on the timing between the decomposition rate of the cover crop residue and the crop demand (Kliemann et al., 2006). Wyland et al. (1996) reported that incorporation of cover crops, specifically phacelia (*Phacelia tanacetifolia* cv. ‘Phaci’) and Merced rye (*Secale cereale* cv. ‘Merced’), caused sudden large surges in inorganic N pools, net mineralizable N, and microbial biomass N and C in the surface soil. This subsided within six weeks but did result in increased yield for the broccoli (*Brassica oleracea* var. *italica*) crop in the phacelia treatment. Incorporation includes a conventional tillage operation where it is usual to find larger amounts of

nitrates, which may be related to the increased mineralization of organic matter in this type of soil management after plowing (Fageria, 2009; Veiga et al., 2010). Without a tillage operation, Ranells and Waggoner (1992) reported that N release rate from crimson clover residues was dependent on the growth stage at which the plant was chemically terminated. The study showed that after 16 weeks of decomposition, 81%, 71%, and 70% N was released for late vegetative, early bloom, and late bloom growth stages, respectively. This suggests that incorporation of cover crops and early termination may be a viable management option if soil N is required for the following crop within a short period of time.

### **1.2.3 Factors Affecting Cover Crop Biomass and Weed Suppression**

#### *Seeding Rates*

It is widely known that benefits of planting cover crops may include increased weed suppression, improved soil health, increased soil microbial communities, and increased N availability. Cover crop growth and biomass (dry matter accumulation) are critical in all cropping systems and can be impacted by species, seeding rate, and yearly environmental conditions (Brennan and Boyd, 2012). Paustian et al. (1997) also found seeding rates had a significant impact on dry matter production, with growth rates and biomass differing among cover crop species and environmental factors. This is supported by research conducted across multiple latitudes in the northeastern U.S. which showed hairy vetch producing maximum biomass at a lower seeding rate of 15-20 kg ha<sup>-1</sup> among all treatments (Mirsky et al., 2017). Inconsistent biomass results show that more data needs to be collected to address specific species, seeding rates, and environmental challenges.

Studies have shown that residue from winter annual cover crops can provide early – season weed suppression by increasing residue biomass, but not full-season weed control

(Teasdale, 2013). It has been reported that one result of higher cover crop biomass is greater coverage of the soil surface by residue, which can negatively impact weed seed germination and seedling emergence (Teasdale et al., 1991). Competition caused by higher seeding rates of a legume-oat cover crop mixture reduced weed biomass significantly when weeds were abundant (Brennan et al., 2009). Cereal rye is known for its ability to scavenge excess N, prevent erosion, add organic matter, and suppress weeds (Clark, 2007), with common broadcast seeding rates ranging from 100-179 kg ha<sup>-1</sup>. Higher seeding rates (>179 kg ha<sup>-1</sup>) have been found to increase biomass, and reduce weed biomass early in the growing season (Ryan et al., 2011). In contrast, Masiunas et al. (1995) reported seeding density of ‘Wheeler’ rye did not affect rye biomass, weed control, or tomato (*Solanum lycopersicum*) yield, but biomass differed among location and year. This might indicate that higher or lower seeding rates of particular cover crop may influence biomass, which is directly related to weed control (Bybee-Finley et al., 2017), while factors such as planting date, location, and termination date must also be considered.

#### *Mixtures versus Monocultures*

While cover crop mixtures have the advantage of addressing multiple objectives at the same time (White et al., 2015), planting, management, and termination of a monotypic stand is easier in comparison and may provide comparable soil benefits. A six-year study examined the effects of cover crop species and diversity on weed suppression. After two years, cover crop biomass was consistently greater in the mixtures compared with monocultures but results suggest that monocultures of high biomass-producing grasses will provide more effective weed suppression at a lower seed cost than functionally diverse mixtures that include low biomass-producing legumes in warm-season intercrops (Mirsky et al., 2017). Evaluation of monocultures versus mixtures has proven many times that specific monoculture species are able to produce



more biomass (Wendling et al., 2017) and would suggest that monoculture species could effectively help suppress weeds for cash crops if other conditions are favorable.

### *Soil Type*

Most winter cover crops grow well on fertile, well-drained soils in temperate regions, but few studies have evaluated differences for specific soils within those regions. McLeod (1982) reported that cereal rye grows best on well-drained loam or clay loam soils, but even heavy clays, light sands, and infertile or poorly drained soils are feasible. Clovers have also been known to grow on a wide range of soil types (Taylor, 1985), but Knight and Hoveland (1985) reported it does not grow well on calcareous soils or with poor drainage. Not only are soil type differences important for determining crop growth, but nutrient availability as well. Jordan et al. (1996) found that soil texture can be one of the most important factors affecting the availability of N from organic or inorganic N sources for a sandy clay loam and loamy sand soil. Managing cover crops for specific soil types or textures may help address nutrient availability issues, with all other conditions being favorable.

### **1.3 Effects of Winter Cover Crops on Other Soil Fertility Parameters**

Although N is the primary nutrient that cover crops are associated with, other nutrient use efficiencies and soil characteristics can be modified or improved with the implementation of cover crops. Capturing and recycling excess soil nutrients in biomass is one of the most important features of a cover crop. Sundermeier (2010) reported oilseed radish can produce enough biomass to recycle 141 kg ha<sup>-1</sup> of phosphorus (P). This crop residue can release soluble or plant-available P and can be taken up by the crop and reused in the same system (Walker et al., 2006). According to most research, planting covers helps reduce erosion, and thereby reduces P loss. Unlike N, P is not mobile in the soil, with over 90% of P runoff being associated with

attachment to clay soil particles (Hoorman et al., 2009). If adequate ground cover is not achieved, excess P will accumulate in waterbodies from field runoff or industrial discharges (eutrophication), causing algal blooms and limiting oxygen for aquatic life (Conley et al., 2009), which is a cause for environmental concern.

Cover crops may also impact the availability of other nutrients by increasing soil acidification (altering soil pH) through carbon (C) and N cycles. If a soil pH is considered alkaline ( $>7.0$ ), some micro-nutrients like iron, manganese, copper, and zinc will become deficient or unavailable, while a pH of  $<7.0$  will cause deficiencies in N, P, potassium, sulfur, and calcium (LSU AgCenter, 2019). Addition of cover crop may initially cause an increase in soil pH due to decomposition of organic anions and organic N, but pH may decrease if nitrification is involved, depending on N concentrations and plant alkalinity (Yan et al., 1996). Burle et al. (1997) reported that in no-tillage systems, legumes and large additions of organic residues increase SOM, cation exchange capacity (CEC), and nutrient availability.

Addition of SOM is known to increase infiltration, improve soil structure, and be related to soil fertility, but the amount depends on the input of organic material and its decomposition, climate, soil texture, and the rate at which the organic matter is mineralized (Johnston et al., 2009). Organic matter levels can be increased by reducing tillage and implementing winter cover crops by as much as  $2,270 \text{ kg ha}^{-1} \text{ yr}^{-1}$  over conventional tillage (Reicosky et al., 1995), which can ultimately increase crop yields. Systems with inclusion of crops between two cropping periods can improve soil surface cover, nutrient recycling, and organic material addition (Burle et al., 1997).

## **1.4 Effects of Soil Texture and Structure on Crop Growth and Yield**

Soil texture refers to the proportions of sand, silt, and clay and influences nearly every aspect of soil use and management. Sandy or coarsely textured soils are generally less fertile, poor at retaining soil moisture, and have lower organic matter than other soils such as loam or clay textured soils (Crouse, 2017). Loamy or medium-textured soils typically contain more organic matter than sandy soils, are better able to retain moisture and nutrients, and are generally more fertile than sandy soils. Heavier clay or clay loams can be highly fertile but tend to swell when moist, and crack open when dry, which can make managing those fields more challenging. Although clay soils tend to have higher nutrient and water-holding capacity, they are finely textured and somewhat difficult to manage when saturated or extremely dry (Weindorf, 2013). Soils with clay content increases CEC and is able to hold on to more cation nutrients (positive charged), while sandy soils, with lower CEC, allow more leaching of nutrients.

Soil structure is the special arrangement of soil particles with their aggregates and pores and plays a key role in determining crop and vegetation performance (Miedema, 1997). It affects water and air movement in a soil, nutrient availability for plants, root growth, and microorganism activity. Cornell (2019) also found that texture and structure can have a significant effect on potential crop growth and yield, primarily due to pore space, organic matter content, and water and nutrient holding capacity. Research has shown that root growth and distribution can alter water and nutrient uptake, and, hence, plant growth and yield in compacted soils (Unger and Kaspar, 1994). Although soil texture cannot be easily modified (percentage of sand, silt, and clay), structure can be altered by increasing the pore space and improving drainage with the addition of organic matter (Crouse, 2017). Utilization of both legume and non-legume cover crops was found to increase levels of soil organic matter from 4-114% (SARE, 2019). This

modification, through implementation of cover crops, may help maximize plant growth and crop yield regardless of soil type and structure.

Even with benefits such as weed and pest suppression, improved N efficiency, and enhanced long-term soil health, cash crop yield is a significant evaluation tool. If cover crops do not maintain production or increase cash crop yield, producers may be reluctant to adopt this practice. Despite this, other significant benefits that may influence implementation include reduced fertilizer and pesticide costs, erosion control, soil moisture retention, and water quality protection (Clark, 2007).

Soil characteristics that can be modified or improved with cover crops may have a direct effect on growth and yield of subsequent crops, regardless of the type. Soil pH and organic matter are important indicators of soil health, which can affect the absorption of trace elements in crops, thus affect the crop yield and quality (Morgenstern et al., 2009). One study indicated soybean yields were highest in cover crop plots compared with plots without cover crops, but were not affected by tillage type or cover crop species (Shrestha, 2002). Other results indicated legume cover crops increased yield of tomato (Stivers and Shennan, 1991) and strawberry (*Fragaria × ananassa*) (Nwenhouse and Dana, 1989). Sainju and Singh (1997) found that yield increases of summer crops following legumes were equivalent to that produced by fertilizer N at 15-200 kg/ha<sup>-1</sup>. This may be due primarily to variations in the biomass yield and N contributions of the cover crops from one place to another and variation in soil and climatic conditions (Meisinger et al., 1991; Shennan, 1992). Because nutrient supply rates are based on soil characteristics, the proportion of structural components can regulate nutrient availability for a crop during the growing season (Binkley and Vitousek, 1989).

## **1.5 Potential Advantages and Disadvantages of Cover Crops**

Rising fuel and fertilizer costs in recent decades have directed producers to seek other ways to increase production and sustain the land, including planting of soil-enriching cover crops. However, this crop must be managed properly to result in positive financial net returns. According to a survey to U.S. producers in 2017, planted cover crop acreage nearly doubled over the last five years (CTIC, 2017 ), with those numbers expected to increase. Over 86% of producers responded that soil health was the number one key benefit of cover crops, followed by improving yield consistency and yield advantage. Some advantages or benefits are not realized in the first year or two, but over time, cover crops can reduce the need for herbicides, conserve soil moisture, prevent soil erosion, protect water quality and help safeguard personal health (Clark, 2007). Other potential advantages may include reduced compaction, excellent weed suppression, and improvement for beneficial insect habitat. Advantages of cover crops do have costs associated with them, mainly due to land preparation, seed costs, and termination of the cover crop. Costs are variable-dependent but can range from \$59-\$77 ha<sup>-1</sup> (Adusumilli et al., 2018), so successful cover crop growth is essential for maximum return on investment.

Though acreage and cover crop adoption have increased over recent years, risks associated with them may still hinder more wide-spread implementation. Disadvantages or challenges may include potential weed issues in cash crops, pest carryover, allelopathic effects in subsequent crops, and establishment and termination issues (Clark, 2007). As stated earlier, some of the short-term benefits are difficult to quantify, however, issues with pests and cash crops as a result of planting cover crops can impact whether cover crops are planted again. To help address some of these and other challenges, it is critical to manage the crop to maximize success.

## 1.6 Objectives

Even with the increasing interest in soil sustainability, information is still deficient in the southeastern U.S. for regionally-specific soil types and cover crop seeding rates. Data collected in this study will help evaluate the impacts of monoculture species of cover crops while estimating potential net returns. The overall goal of this study was to evaluate the impact of seeding rate of three monoculture winter cover crops on soil health and soybean production across different soil types. More specific objectives included:

Evaluate effects of soil type, cover crop seeding rate, and/or sample date on:

- i. Soil chemical properties (phosphorus, potassium, calcium, magnesium, zinc, copper, nitrate, ammonium, soil pH, CEC, and soil organic matter)
- ii. Weed and cover crop biomass, accumulation of cover crop carbon, nitrogen, total nitrogen, and C:N ratio
- iii. Soybean production (plant height, plant population, grain yield)
- iv. Economic net return estimates for cover crop implementation within species for seeding rates and soil type compared to a standard fallow treatment

## 1.7 Literature cited

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## CHAPTER 2. EVALUATION OF COVER CROP SEEDING RATE AND SOIL TYPE ON CHEMICAL SOIL PROPERTIES

### 2.1 Introduction

Determining which cover crop species, or mixture of species, to integrate into a crop production system is dependent on the grower's primary purpose for planting the cover crop, as well as geographic location. Secondary objectives may include supplying chemical nitrogen (N) to the succeeding crop and reduce N fertilizer use, reducing nitrate ( $\text{NO}_3^-$  - N) leaching, and/or improving soil properties (Meisinger et al., 1991) such as soil structure, tilth, and aggregation. Many studies focus on determining which cover crop monoculture or polyculture provides the most biomass and release plant-available N throughout the growing season (Daniel et al., 1999; Couëdel et al., 2018). Although Teasdale and Abdul-Baki (1998) found that cover crop mixtures of cereal rye (*Secale cereale*), and hairy vetch (*Vicia villosa*) and cereal rye and crimson clover (*Trifolium incarnatum*) both had greater biomass than hairy vetch alone, questions still persist regarding their use, mainly due to management issues and increased associated costs.

Cereal rye is a member of the wheat family (*Triticeae*) and is a popular grass cover crop because of its potential for high biomass and rapid increased soil organic matter (Snapp et al., 2005). Cereal rye is known for its extensive, fibrous root systems and is able to take up a significant proportion of residual soil  $\text{NO}_3^-$  -N without affecting soybean (*Glycine max* L) grain yield while reducing leaching potential (Ruffo et al., 2004). It is also known for its excellent weed suppression, with weed biomass decreased with increasing cereal rye residue ranging from 0.5-1.3 mg ha<sup>-1</sup> in a study conducted in upstate New York (Liebert et al., 2017). Other research in the northern mid-Atlantic region measured average cereal rye biomass of 4200 kg ha<sup>-1</sup> of dry matter at the late-boot stage and did not reduce corn (*Zea mays*) yields if killed 7-10 days before corn planting compared with a unplanted control plot (Duiker and Curran, 2005).

Crimson clover is a winter annual, usually planted in late summer to early fall and used in pastures, organic farming and as a cover for soil protection (USDA, 2002). As a legume, crimson clover is used extensively as a cover crop as far north as Maine. Legume cover crops provide substantial amounts of N through biological N fixation to the succeeding crop (Frye et al., 1988; Hargrove, 1986; Smith et al., 1987; Touchton et al., 1984; Vigil and Kissel, 1991) and can increase the yield of summer crops that require N early in the season. Differences in yield from legume versus non-legume cover crop are due mainly to chemical composition, like carbon to nitrogen (C:N) ratio (Kuo et al., 1996), and lignin, hemicellulose, and cellulose content. Crimson clover, like many legumes, has lower C:N ratios than grasses or brassicas (at the same growth stage), and with humid, subtropical conditions, release of N can be rapid enough to be of significant benefit to the summer crop (Wilson and Hargrove, 1986) if termination is timed correctly.

Tillage radish (*Raphanus sativus* L. var. *niger* J. Kern.), also known as Daikon or Japanese radish, has been effective in reducing soil  $\text{NO}_3^-$ -N leaching (Isse et al., 1999) and helping alleviate soil compaction in drought-prone soils. Soil compaction can be an issue with specific soil types and management systems resulting in reduced water infiltration, minimal pore space for gas exchange, and reduction in root growth. Williams and Weil (2004) found that soybean yields were significantly greater following a forage radish and rye combination in a study that evaluated cover crop effects on soil compaction. Radishes can also influence P cycling because of its high tissue P concentration, rapid growth in the fall and rapid decomposition in winter and spring. White and Weil (2011) found that soil within 3 cm of a radish taproot hole had greater Mehlich III extractable P concentrations than radishes and cereal rye in bulk soil.

Regardless of cover crop species, the implementation of cover crops and organic inputs can yield higher soil organic C, soluble P, exchangeable potassium, and pH (Clark et al., 1998).

Seeding rate recommendations for cover crops vary across regions, planting method, species, and variety. Interestingly, higher seeding rates do not always produce the greatest biomass. In a study evaluating seeding rates and planting arrangements in an organic vegetable system, Brennan et al. (2009) found that increasing typical seeding rates from 112 kg ha<sup>-1</sup> to 336 kg ha<sup>-1</sup> increased early season cover crop dry matter production but did not affect the final dry matter of the cover crop. A cover crop biomass experiment conducted in five northeastern states concluded that hairy vetch produced maximum biomass at seeding rates of 15-20 kg ha<sup>-1</sup>, at the low end of currently recommended rates of 18-22 kg ha<sup>-1</sup>, while other results indicated maximum biomass at 5-10 kg ha<sup>-1</sup> (Mirsky et al., 2017). This would indicate that there may be significant variation in optimal seeding rates for maximum biomass, which can be directly correlated to weed suppression, available inorganic N, and ground cover.

Soil type variation inherently has different chemical properties that may influence crop growth and yield potential, including organic matter content. Fine-textured soils, with high percentages of clay and silt, tend to have naturally higher amounts of soil organic matter than course-textured soil (Magdoff and Van Es, 2009), but this may not always correlate to higher growth or yields. The amount of clay present is a prime consideration in the composition of the soil and has a highly important effect on its properties (Newman, 1984). To address challenges with varying soil types, Unger (1979) classified problems for high clay horizon soils (that could be alleviated by profile modifications) to include reduced root penetration, poor infiltration of water, poor water storage and drainage, and poor leaching. In contrast, problems for sandy soils included excessive percolation, low fertility, excessive leaching, and high wind erosion. Because



pore size and aggregate stability associated with both soil types can impact water and nutrient holding capacity, as well as compaction, management for each soil type must be considered.

Interest in cover crops in Louisiana has spanned over 60 years with some of the earliest studies evaluating the effects of winter cover crops on certain physical properties of Commerce loam soils from the early 1950's (Patrick et al., 1957). Other research has included evaluating impacts of tillage systems in winter cover crops on cotton maturity and yield on a Loess soil (Hutchinson et al., 1993). More current studies are evaluating winter and summer cover crops species across soil types, planting and termination dates, N accumulation from cover crops in a corn production system, and more recently, seeding rates. The goal of this study was to evaluate the effects of soil type and broadcast seeding rates for three winter cover crops species and their impact on soil chemical properties in a soybean production system in two soil types. The hypothesis is that seeding rates will affect inorganic N levels across the course of this study, with fluctuations in other macro and micronutrients. Additionally, soil organic matter will not increase significantly due to initial tillage operations and relatively short length of time.

## **2.2. Materials and Methods**

### **2.2.1 Site Characteristics**

A two-year non-irrigated experiment was conducted at the LSU AgCenter Dean Lee Research and Extension Center, located 9.7 km south of Alexandria, Louisiana from 2016 to 2018. This study utilized three monoculture species from the legume, brassica, and grass families that were adapted to the southern United States. Species included Elbon cereal rye (*Secale cereale*), Daikon tillage radish (*Raphanus sativus* L.), and AU Sunrise crimson clover (*Trifolium incarnatum*) and were evaluated at low, medium, and high seeding rates in addition to a control plot with no cover crops planted. Cover crops were broadcast using seeding rates obtained from

USDA-NRCS Cool Season Cover Crop Species & Planting Dates TX-PM-15-03 2015 and AL Extension ANR-2139 publications (Table 2.1).

Field locations included two areas with classified soil textures of clay and silt loam, specifically Moreland clay (MCI) and Couthatta silt loam (CSL) soils (Figure 2.1). These were located approximately 0.8 km apart on 0-1% slope.

Table 2.1. Seeding rate treatments for cover crop species in kg ha<sup>-1</sup> based on recommended broadcast rates

Cover Crop Species/Variety	Low Rate	Medium Rate	High Rate
kg ha <sup>-1</sup>			
Daikon radish	7.9	11.2	14.6
AU Sunrise crimson clover	24.7	29.1	33.6
Elbon rye	62.8	98.6	134.5

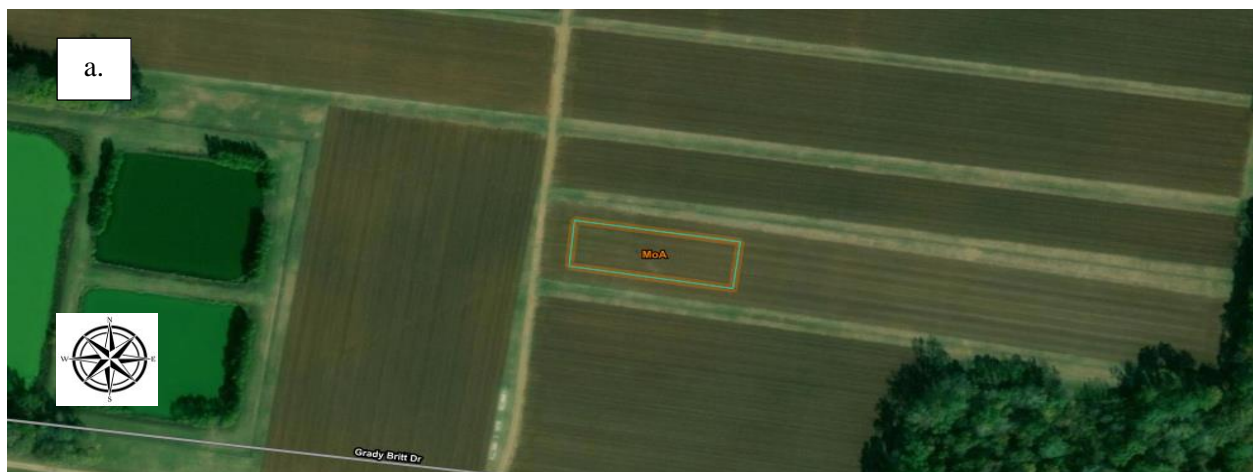


Figure 2.1. Aerial view of (a) Moreland clay (Latitude, Longitude 31.178029 °N,-92.410545°W) and (b) Couthatta silt loam research plots (Latitude, Longitude 31.178047°N,-92.410498°W)

Figure continued.



The MCI soil was classified as a very-fine, semiotic, thermic Oxyaquic Hapluderts and considered a very deep, somewhat poorly drained, permeable soil (USDA, 2019). In contrast, the CSL classified as a fine-silty, mixed, superactive, thermic Fluventic Eutrudept soil that is very deep and well-drained (USDA, 2011). According to United States Department of Agriculture (USDA, 1997) both soil types are considered Prime Farmland and suitable for growing crops. Previous crop rotations for each soil type included soybean and cotton (*Gossypium hirsutum*).

### **2.2.2 Experimental Design and Field Management**

The experimental design was a randomized complete block of ten treatments with three replications. Plots consisted of four, 96.5 cm rows x 12.2m in length ( $\sim 49 \text{ m}^2$ ) with the two middle rows used for data collection. Nine seeding rate treatments were randomly assigned within each rep, in addition to an untreated control treatment (Figure 2.2).

Initial field preparation included mechanically incorporating soybean residue from the previous crop and rows were conventionally prepared for cover crop planting using a Case International 235 Magnum tractor and cultivator equipment.

According to initial soil test recommendations,  $P_2O_5 + K_2O$  was broadcast at rates of 35.1 and 70.6 kg ha<sup>-1</sup>, respectively, to each plot on October 1, 2016. Subsequent soil test recommendations in 2017 increased application rates of  $P_2O_5 + K_2O$  to 45.4 kg ha<sup>-1</sup> and 90.8 kg ha<sup>-1</sup>. Seeds were broadcast onto prepared beds with an Earthway 3400 Ergonomic Hand-Held Broadcast spreader on October 17, 2016 and November 6, 2017, respectively.

110 CC L	109 RYE M	108 RAD H	107 CC M	106 RYE L	105 CC H	104 RAD M	103 FALL	102 RYE H	101 RAD L
210 RAD H	209 CC M	208 RYE M	207 RAD L	206 RYE H	205 CC L	204 CC H	203 RYE L	202 RAD M	201 FALL
310 CC M	309 RAD L	308 FALL	307 RAD M	306 RAD H	305 RYE H	304 CC H	303 RYE M	302 CC L	301 RYE L

Figure 2.2. Field experimental design with cover crop species (crimson clover [CC]; cereal rye [RYE]; tillage radish [RAD]; fallow [FALL]) and randomized seeding rates (low [L]; medium [M]; high [H]).

Planting dates were one-week post and prior to soil sample collections (for 2016 and 2017, respectively) due to fall field preparation timing. Beds were immediately rolled with a culti-packer to ensure optimum seed-to-soil contact. Plots were non-irrigated and cover crops were planted into dry soil conditions after soybean harvest for both years, which delayed emergence until approximately mid-November (Figure 2.3).

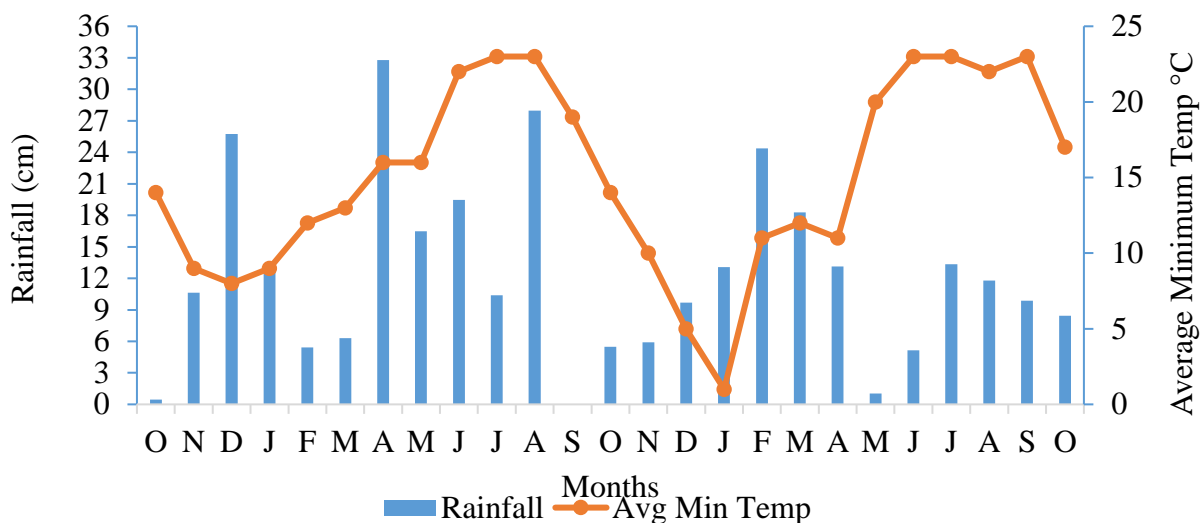


Figure 2.3. Monthly precipitation and average minimum temperatures recorded during cover crop planting until soybean harvest 2016-2018 at Dean Lee Research Station Weather Station, Alexandria, Louisiana.

### 2.2.3 Soil Sampling and Analysis

Three soil samples were randomly collected from each plot at 0-15 cm depth prior to cover crop planting (October 10, 2016), after cover crop termination (March 20, 2017 and April 4, 2018), and after soybean harvest (October 30, 2017 and October 7, 2018) to evaluate any changes in soil health characteristics that may have occurred during that time. A standard soil probe (2.5 cm diameter) was used to collect a composite sample and refrigerated subsamples were sent to LSU AgCenter Soil Testing and Plant Analysis Laboratory (STPAL) in Baton Rouge, LA. All soil samples collected were subject to analysis for routine chemical and specific soil properties. These included macro and micro-nutrients, as well as soil pH, cation exchange capacity (CEC), and soil organic matter (SOM).

Routine soil chemical analysis for Phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), sulfur (S), copper (Cu), and zinc (Zn) were analyzed using the Mehlich III extraction (2 g soil / 20 mL solution) with ICP inductively coupled plasma method

(Mehlich, 1984). Soil pH was measured in 1:1 in deionized water:soil solution with a pH meter + electrode (McLean, 1982). Soil organic matter was determined by using a 1:10 deionized soil:water solution with an acid-dichromate oxidation extractant (Nelson and Sommer, 1996), and soil texture was determined by hand. Cation exchange capacity was estimated using a fixed value for each soil texture + (two x percent soil organic matter).

Inorganic N analysis was extracted using 10 ml of 2 *M* KCl per 1 g soil. Colorimetric analysis was done according to the method described by Hood-Nowotny et al. (2010). For  $\text{NH}_4^+$ -N, 96-well microplates were filled with a salicylate solution. The filtered sample was added before the second reagent, bleach/NaOH, was also added. Plates were then incubated in the dark for 50 minutes at room temperature. For  $\text{NO}_3^-$ -N, 96-well microplates were filled with a vanadium chloride solution after which the filtered sample was added. These plates were then incubated in the dark for 60 minutes at 37°C. Absorbance was measured on an EON spectrophotometer by BioTek at 660 nm for  $\text{NH}_4^+$ -N concentration and 540 nm for  $\text{NO}_3^-$ -N concentration.

#### **2.2.4. Statistical Analysis**

Data were analyzed using the Mixed Model Analysis of Variance (%MMOV). Dependent variables included soil pH, ammonium, nitrates, phosphorus, potassium, magnesium, zinc, copper, sulfur, cation exchange capacity, and soil organic matter, while independent variables were sampling date, cover crop seeding rate and soil type. Replication was considered a random effect. Soil chemical data were analyzed using Glimmix Procedure of SAS release 9.4, (SAS Institute Inc. 2013. SAS/STAT® 13.1 User's Guide. Cary, NC: SAS Institute Inc.) and means were separated using the Fisher's Least Significant Difference with the LSD option of the MEANS statement. An  $\alpha \leq 0.05$  was considered significantly different for all procedures.

## 2.3 Results and Discussion

### 2.3.1 Macro- and Micro-nutrients

Initial chemical analysis (fall of 2016) of specific soil parameters indicated the different characteristics of each soil type and indicate how this may have affected nutrient availability throughout the course of this study (Table 2.2).

Table 2.2. Selected characteristics of the two soils used in this study.

Soil Type <sup>†</sup>	pH <sup>‡</sup> (1:1 water)	Mehlich-III Phosphorus	Soil Organic Matter	Cation exchange capacity (CEC)	NH <sub>4</sub> <sup>+</sup> -N	NO <sub>3</sub> <sup>-</sup> -N
		g kg <sup>-1</sup>	%	meq 100g <sup>-1</sup>	mg kg <sup>-1</sup>	
CSL <sup>†</sup> soil	8.2	25	1.8	9.0	– <sup>§</sup>	–
MCl soil	7.9	86	3.2	15.4	0.78	1.2

<sup>†</sup>CSL = Coushatta silt loam and MCl = Moreland clay

<sup>‡</sup> Soil pH was measured in a ratio of 1:1 (soil:water)

<sup>§</sup>Initial sample was unavailable.

Significant differences across sample collection dates were noted for all nutrients with the exception of magnesium (Table 2.3). Over time, (from the fall of 2016 until the fall of 2018),

Table 2.3. Differences in soil nutrients by sample collection dates (standard errors are in parenthesis).

Nutrient	FALL2016	SPR2017	FALL2017	SPR2018	FALL2018	<i>P value</i>
Calcium	6388 (191) a <sup>†</sup>	6286 (235.2) ab	5703 (147.7) c	5723 (147.3) c	5965 (165.6) bc	<0.0001
Copper	4.2 (0.4) a	3.9 (0.2) b	3.3 (0.2) c	3.3 (0.2) c	3.3 (0.2) c	<0.0001
Magnesium	717 (31.2) ab	704 (23.9) ab	730 (31.7) a	688 (29.8) b	697 (32.5) ab	0.2820
Potassium	369 (26.5) b	327 (19.4) c	389 (33.1) a	339 (25.3) c	332 (25.1) c	<0.0001
Phosphorus	56 (4.6) a	44 (3.7) b	45 (3.8) b	40 (3.2) b	40 (3.4) b	<0.0001
Sulfur	109 (18.5) a	47 (8.3) b	34 (5.5) bc	20 (1.9) c	14 (0.9) c	<0.0001
Zinc	1.9 (0.07) b	2.1 (0.06) a	1.9 (0.09) b	1.8 (0.07) bc	1.7 (0.06) c	<0.0001

<sup>†</sup>Different letters denote differences ( $\alpha=0.05$ ) between sample dates within each nutrient.

all nutrient levels were lowered 7-88%. This may have been attributed to nutrient removal from both cover crops and soybean harvest over the course of the study. Although most nutrients fluctuated over sampling dates, S levels consistently decreased throughout the study. Most nutrients are not mobile in the soil, but S, like N, is highly mobile and reductions may be due to heavy rainfall events during the winter months and leaching potential of the soil. Cover crop biomass and root mass during those sampling periods may not have been sufficient to help reduce some of this potential leaching. Even though P and K were applied in the fall of each year, concentrations were reduced by the end of the study as well.

The availability of mineral elements to plants is dependent on their form and solubility, on the presence of competing entities, and on environmental factors such as pH, moisture, weed competition, and temperature (Horsfall and Cowling, 1980). Soil pH levels were significantly impacted by sample date, cover crop seeding rate, and soil type ( $P < 0.0001$ ). Across both soil types, pH was lowest in the FALL2017 at 7.95 and highest in the SPR2018 at 8.15. Cover crop seeding rates affected soil pH over the course of this study, specifically within crimson clover and cereal rye (Figure 2.4). Coughatta silt loam soil pH was greater than MCI at 8.15 and 7.93, respectively. Both soils were considered highly alkaline, which can restrict many micronutrients from being available thereby reducing the potential for nutrient uptake. Routine soil analysis does not include iron, however, deficiencies were noted during the summer of 2018 in the CSL soybean plots. A visual assessment concluded approximately 20% of the plot was affected but resulted in no yield differences at harvest. This may have been related to excessively dry soil conditions in a light textured soil (CSL) or due to the alkaline nature of the soil causing ferrous iron to be oxidized to the ferric form, which is not available for growth (Horsfall and Cowling, 1980).



As cover crops and soybeans were planted and harvested, nutrient levels fluctuated, but there were no interactions between sample date and cover crop seeding rate. However, cover crop seeding rate had a significant effect on nutrient levels, with the exception of S ( $P=0.485$ , Table 2.5). Significant differences in nutrient concentrations were also measured for soil type across all nutrients ( $P<0.0001$ , Table 2.7). These results are not surprising due to basic soil characteristics for silty loam and clay soils, depending on the proportion of sand and clay, which can influence nutrient holding capacity.

Interactions occurred for soil type by sample date and soil type by cover crop seeding rate for many of the nutrients. This suggests that nutrient levels changed over time and over different environmental conditions, in response to seeding rate and soil type.

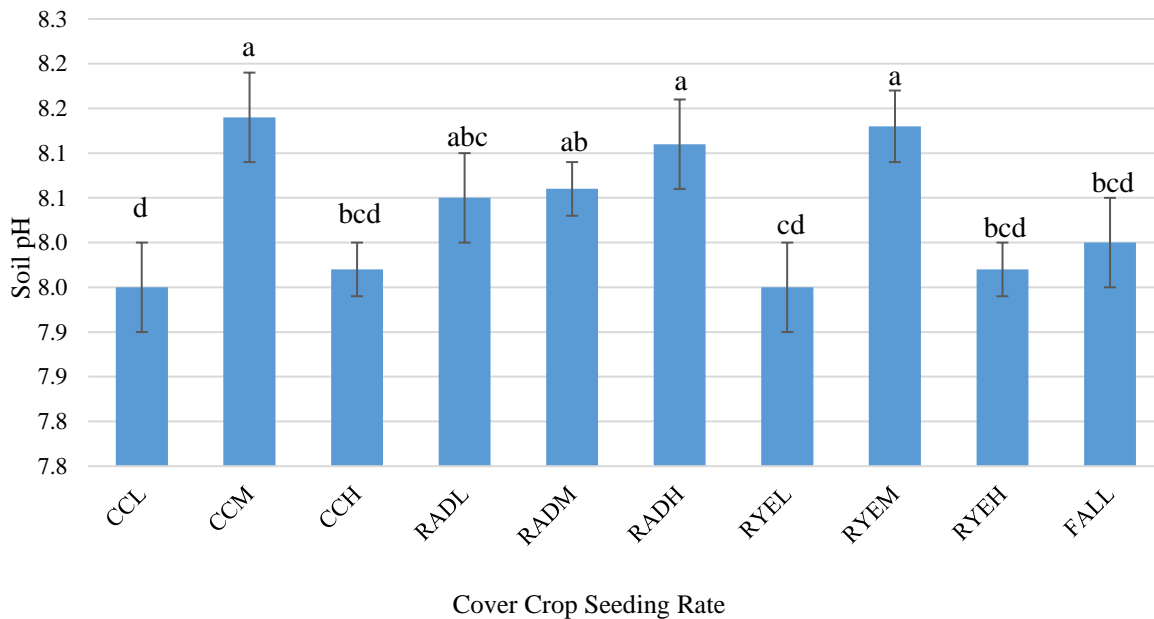


Figure 2.4. Soil pH for cover crop seeding rates. Bars with different superscripts are significantly different ( $\alpha=0.05$ ).

Table 2.5. Differences in nutrient concentrations within each cover crop seeding rate (standard errors are in parenthesis).

Cover Crop and Rate†	Ca	Cu	K	Mg	Na	P	S	Zn
	mg kg <sup>-1</sup>							
CCL	5721(299)de‡	3.7(0.4)ab	373(39.7)a	714(52.4)b	93(22.5)c	47.5(4.9)ab	32.3(8.9)a	2.1(0.10)a
CCM	6704(262)a	3.5(0.4)bc	337(36.8)d	727(33.4)ab	187(57.5)ab	34.8(4.2)c	59.9(15.7)a	1.8(0.10)bc
CCH	5535(299)e	3.7(0.4)ab	342(39.7)cd	712(52.4)b	164(22.5)abc	45.3(4.9)b	48.7(8.9)a	1.8(0.10)bc
RADL	6515(258)ab	3.4(0.4)c	350(38.2)bcd	684(32.7)b	147(44.4)abc	44.4(6.6)b	52.2(19.6)a	1.9(0.13)bc
RADM	5989(198)cde	3.6(0.4)bc	342(33.7)cd	671(42.6)b	130(35.6)abc	43.4(5.1)b	39.1(13.0)a	1.7(0.09)c
RADH	6246(287)abc	3.6(0.4)abc	345(39.2)cd	773(31.1)a	205(55.9)a	44.8(6.1)b	61.1(19.0)a	1.9(0.10)bc
RYEL	5583(247)e	3.8(0.4)a	369(38.0)ab	722(51.2)ab	104(29.1)c	53.4(5.8)a	43.1(18.6)a	2.1(0.12)a
RYEM	6189(274)bcd	3.6(0.4)bc	339(39.6)cd	692(35.8)b	92(22.7)c	46.0(6.2)ab	38.5(10.7)a	1.8(0.09)bc
RYEH	5630(224)e	3.7(0.4)ab	355(38.3)abcd	684(52.2)b	101(28.6)c	44.6(4.6)b	37.0(13.7)a	1.9(0.12)bc
FALL	6021(262)cde	3.6(0.4)bc	360(37.5)abc	692(44.7)b	114(25.5)bc	44.5(5.5)b	34.3(7.6)a	1.9(0.10)ab
<i>P value</i>	<i>&lt;0.0001</i>	<i>&lt;0.0001</i>	<i>0.009</i>	<i>0.033</i>	<i>0.023</i>	<i>0.007</i>	<i>0.485</i>	<i>0.0001</i>

† CC=crimson clover; RAD = tillage radish; RYE = cereal rye; L = Low; M = Medium; H = High

‡ Different letters denote differences ( $\alpha=0.05$ ) between cover crop seeding rates

Table 2.6. Nutrient concentrations for each soil type (standard errors are in parenthesis).

Soil Type	Ca	Cu	K	Mg	Na	P	S	Zn
	mg kg <sup>-1</sup>							
Coushatta silt loam	6898(105.69)a†	1.7(0.05)b	157(2.96)b	520(12.72)b	242(20.43)a	20.9(0.53)b	81.6(8.23)a	1.5(0.03)b
Moreland clay	5128(71.9)b	5.5(0.07)a	545(6.25)a	894(9.52)a	24.8(0.92)b	68.8(1.92)a	7.6(0.25)b	2.3(0.03)a
<i>P value</i>	<i>&lt;0.0001</i>	<i>&lt;0.0001</i>	<i>&lt;0.0001</i>	<i>&lt;0.0001</i>	<i>&lt;0.0001</i>	<i>&lt;0.0001</i>	<i>&lt;0.0001</i>	<i>&lt;0.0001</i>

† Different letters denote differences ( $\alpha=0.05$ ) across soil types within each nutrient

Results for inorganic N indicated a consistent soil type effect across sample collection dates for  $\text{NO}_3^-$ -N levels ( $P<0.0001$ ). Evaluation within each soil type resulted in differences across sampling date ( $P<0.0001$ ) for CSL soil, with an interaction occurring between sampling date by cover crop seeding rate ( $P=0.0007$ ). Nitrate levels were highest in SPR2017 and decreased throughout soybean harvest, with lowest levels in SPR2018 (3.6 and 0.54  $\text{mg kg}^{-1}$ , respectively). This may be due to soybean utilization of soil  $\text{NO}_3^-$  throughout the growing season, leaching, or low N inputs from reduced cover crop biomass in the spring of 2018 (Figure 2.5). Post-soybean harvest residual N in the fall of 2018 may have helped to increase  $\text{NO}_3^-$  levels from 0.54 to 1.25  $\text{mg kg}^{-1}$ .

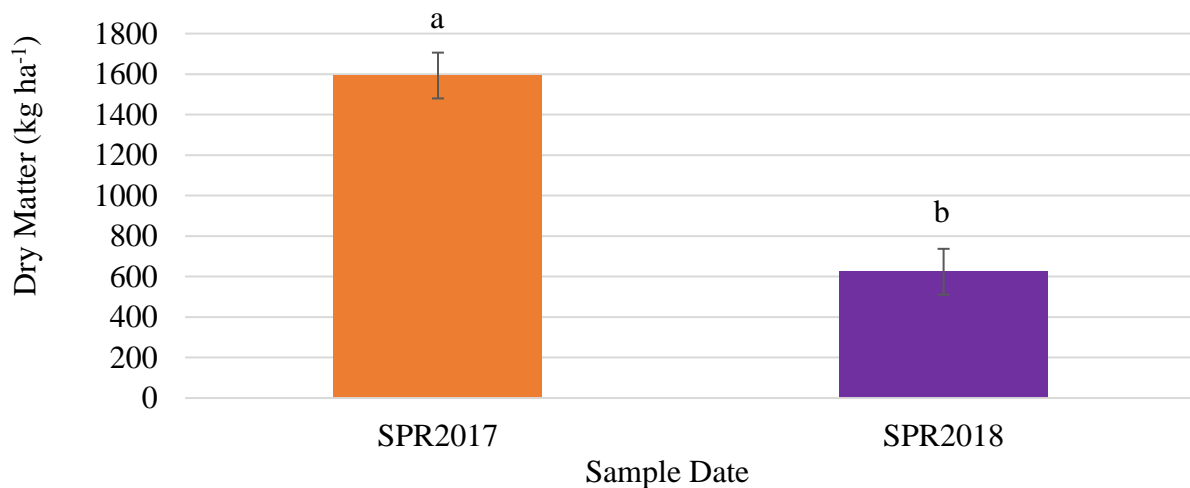


Figure 2.5. Cover crop dry matter accumulation across sample dates in spring (SPR) 2017 and 2018. Bars with different superscripts are significantly different ( $\alpha=0.05$ ).

Interactions occurred between sampling date by cover crop seeding rate ( $P=0.0007$ , Figure 2.6), for CSL soil. Overall  $\text{NO}_3^-$  levels were highest in the SPRING of 2017 and were lower across sample dates with the exception of SPRING 2018.

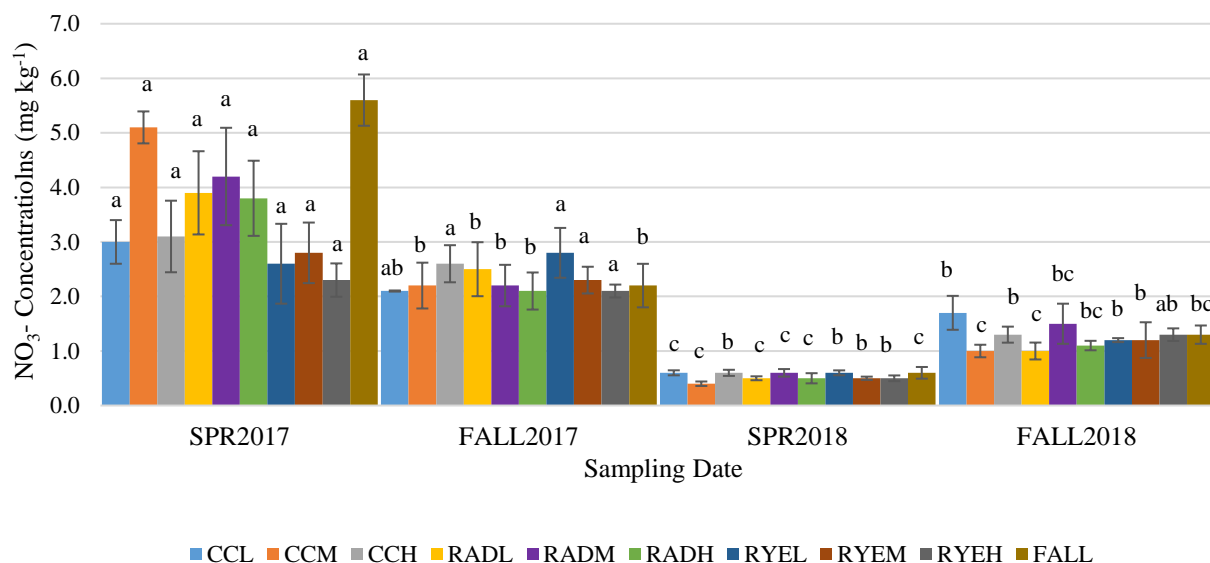


Figure 2.6. Soil  $\text{NO}_3^-$  concentrations for sampling date by cover crop seeding rate in Coushatta silt loam soil (CSL). Bars with different superscripts are significantly different ( $\alpha=0.05$ ). CC = crimson clover; RAD = tillage radish; RYE = cereal rye; L = Low; M = Medium; H = High

Results for the MCI soil showed differences in sample date ( $P < 0.0001$ ), but not for cover crop seeding rate ( $P = 0.303$ ). Nitrate levels for SPR2017 were significantly lower than all other sample dates (0.29, 1.59, 0.44, 0.55  $\text{mg kg}^{-1}$ , respectively). Low levels in the spring may have been impacted by heavy winter precipitation in 2016 that caused soil  $\text{NO}_3^-$  losses through denitrification or leaching. No differences were measured between SPR2018 and FALL2018 sample dates (Figure 2.7). Although the CSL soil  $\text{NO}_3^-$  levels peaked across most seeding rates in the SPR2017, MCI's highest level was in FALL2017 (1.59  $\text{mg kg}^{-1}$ ). Factors affecting soil  $\text{NO}_3^-$  levels include residual soil N, precipitation, and N inputs (Geisseler and Horwath, 2016), which could have influenced  $\text{NO}_3^-$  N in both soils over the course of the study. Research conducted by Gaines and Gaines (1994) also found that soil texture affected the retention of  $\text{NO}_3^-$  N, with a sandy clay loam (which had the finest soil texture and highest CEC), adsorbed the

highest amount of  $\text{NO}_3^- \text{N}$  compared with a loamy sand and mix of sand and sphagnum peat moss.

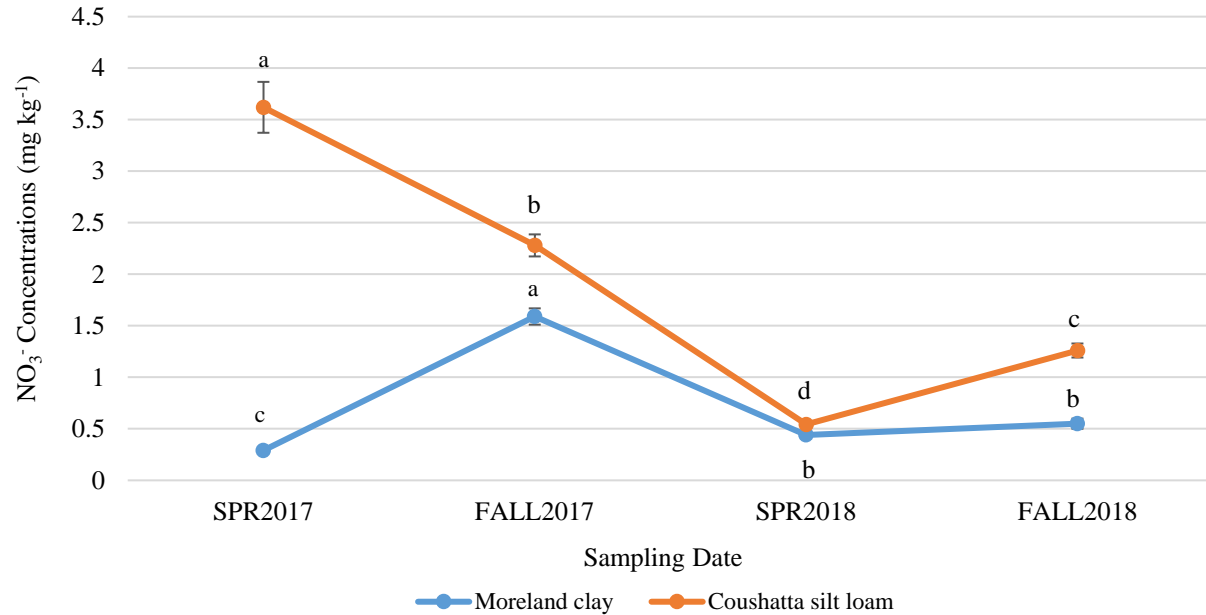


Figure 2.7.  $\text{NO}_3^-$  concentrations in Moreland clay (MCI) and Coughatta silt loam (CSL) by sample date. Bars with different superscripts are significantly different ( $\alpha=0.05$ )

Ammonium-N was affected by soil texture and sampling date ( $P < 0.0001$ ) with the highest concentrations measured in the MCI in the spring of 2018 ( $0.459 \text{ mg kg}^{-1}$ , Figure 2.8), however, cover crop seeding rate had no effect on CSL or MCI soil ( $P = 0.804$  and  $0.168$ , respectively). Ammonium levels for MCI soil in FALL2018 were significantly lower than all other sampling dates ( $0.262 \text{ mg kg}^{-1}$ ), but greatest in the spring for both years ( $0.398$  and  $0.459 \text{ mg kg}^{-1}$ , respectively). Coughatta silt loam results indicated  $\text{NH}_4^+$  levels were greater in FALL2018 than FALL2017 and SPR2018 dates, but not for SPR2017 ( $0.348$ ,  $0.25$ ,  $0.275$ , and  $0.409 \text{ mg kg}^{-1}$ , respectively). This supports research that evaluated N availability in acidic and calcareous soils, which concluded that seasonal fluctuations affected N availability, with

maximum levels in the late winter/early spring and then progressively declined to low levels in the summer months (Taylor et al., 1982).

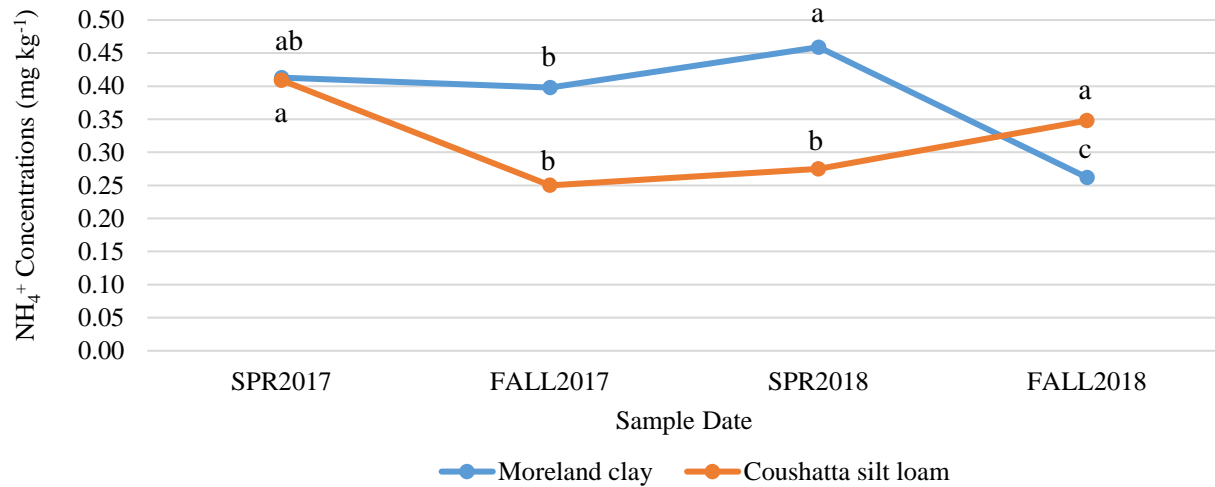


Figure 2.8. Ammonium levels for Coughatta silt loam (CSL) and Moreland clay (MCI) soils by sample date. Bars with different superscripts are significantly different ( $\alpha=0.05$ )

### Soil pH

One goal of establishing cover crops into a production management system is to improve soil health, including balancing essential nutrients and utilizing nutrient efficiency. One primary way to do this is adjusting soil pH to allow micronutrients to become more available to the plant, thereby improving nutrient efficiency. Due to the limited resources and difficulty in lowering soil pH in a short period of time, the pH for both soil types in this study were not able to be adjusted, which may have impacted the soil nutrient levels over time.

Soil pH was significantly affected by soil type, cover crop seeding rate, and sample date ( $P < 0.0001$ ). Although both soils are considered highly alkaline, CSL soil pH was greater than MCI (8.15 and 7.93 pH, respectively). Cover crop seeding rate showed significant differences

across treatments with soil pH ranging from 7.95 to 8.15 (Appendix). Across both soil types, soil pH was impacted by sample date with the FALL2016 pH lower than that of SPR2018, but not for SPR2017, FALL2017, or FALL2018 (8.02, 8.14, 8.08, 7.96, and 8.0 pH, respectively). After the initial sample collection date of FALL2016, pH increased in the spring after cover crop termination and decreased in the fall after soybean harvest (Figure 2.8). This could be due to the soils' inherent ability to acidify over time in warm climates and heavy rainfall, in addition to the soils leaching potential, which can cause decreases in soil pH (Carver and Ownby, 1995). Additionally, leguminous crops (both cover crops and soybeans) that fix atmospheric N<sub>2</sub> involve the excess uptake of nutrient cations over anions from the soil solution, resulting in a lower soil pH (Haynes, 1983).

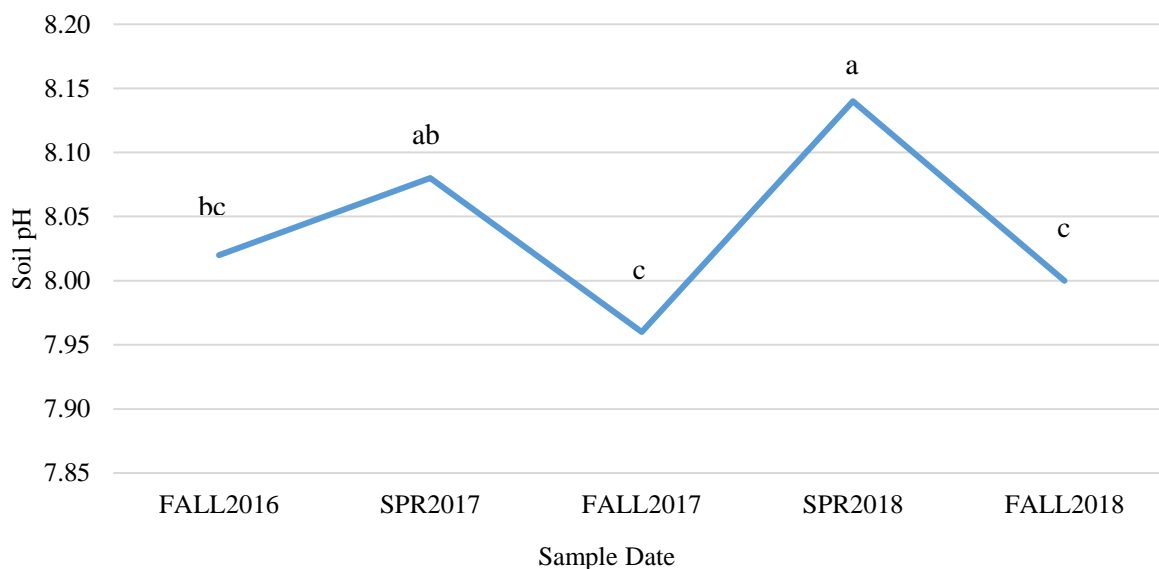


Figure 2.9. Soil pH levels across sampling dates for Coughatta silt loam and Moreland clay soils. Bars with different superscripts are significantly different ( $\alpha=0.05$ )

### *Soil Organic Matter*

It is well known that organic matter, made up of living organisms, fresh residues, and well-decomposed residues and is critical in nutrient cycling (SARE, 2010), is one of the key

evaluation tools in soil health, and therefore can be a good indication of productivity. Initial organic matter levels (FALL2016) averaged 1.8% for CSL and 3.2% for MCI, with the normal range of organic matter levels in Louisiana soils ranging from 2-5% (Weindorf, 2013).

Differences were found across sample date ( $P < 0.0001$ ), cover crop seeding rate ( $P = 0.0005$ , Appendix), soil type ( $P = 0.0001$ ), and interactions occurred between sample date by soil type ( $P < 0.0001$ ) and cover crop seeding rate by soil type ( $P = 0.0126$ ). Initial sample date levels were greater than all other sampling dates at 2.52% (Figure 2.10). Differences in organic matter levels were found across all sample dates with the exception of SPR2018 and FALL2018 (1.94% and 1.91%, respectively). While it is known that abiotic variables such as temperature and moisture affect the decomposition of organic matter, soil structure and texture, and microbial populations may also play an important role in these fluctuations (Van Veen and Kuikman, 1990). Temperature fluctuations, heavy rainfall, and residue decomposition may have affected organic matter levels at selected sampling dates, but ultimately levels did not increase by the end of the study.

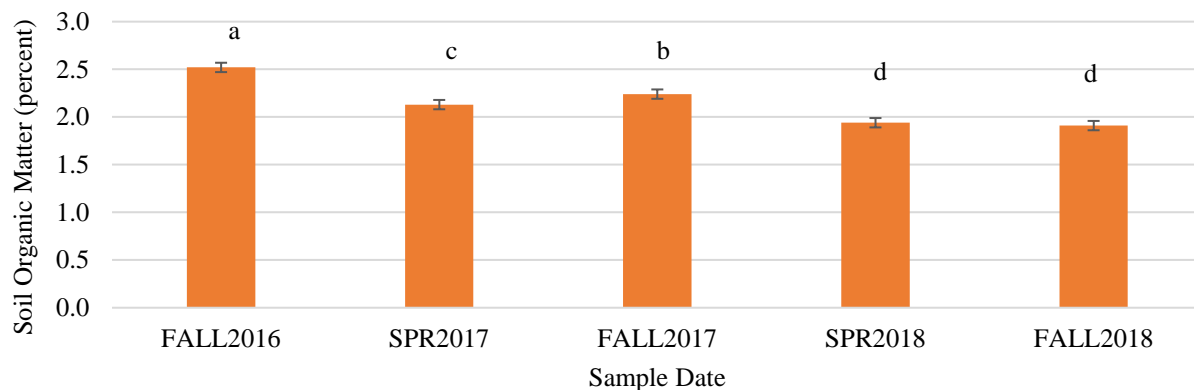


Figure 2.10. Soil organic matter levels across sample dates for Coughatta silt loam (CSL) and Moreland clay (MCI) soils. Bars with different superscripts are significantly different ( $\alpha=0.05$ ).



## CEC

Cation exchange capacity is defined as the soil's ability to hold onto essential nutrients (Ca, Mg, K, and Na) and provides a buffer against soil acidification (Ketterings et al., 2007). This value is a good indicator of the organic matter and water holding capacity of the soil. Results for CEC indicated significant differences for sample date ( $P < 0.0001$ ), soil type ( $P < 0.0001$ ), cover crop seeding rate ( $P = 0.167$ ), with an interaction for sample date by soil type ( $P < 0.0001$ ). Initial sample date CEC value was  $11.98 \text{ meq } 100\text{g}^{-1}$  in FALL2016, then increased by 36% in SPR2017 (Figure 2.11). Values were lower in FALL2016 than all other sample dates, with SPR2017 equal to FALL2017, but greater than both sample dates in 2018. Fluctuations in CEC values over sample date are directly correlated to the essential nutrient values that also varied over sample date (Table 2.5).

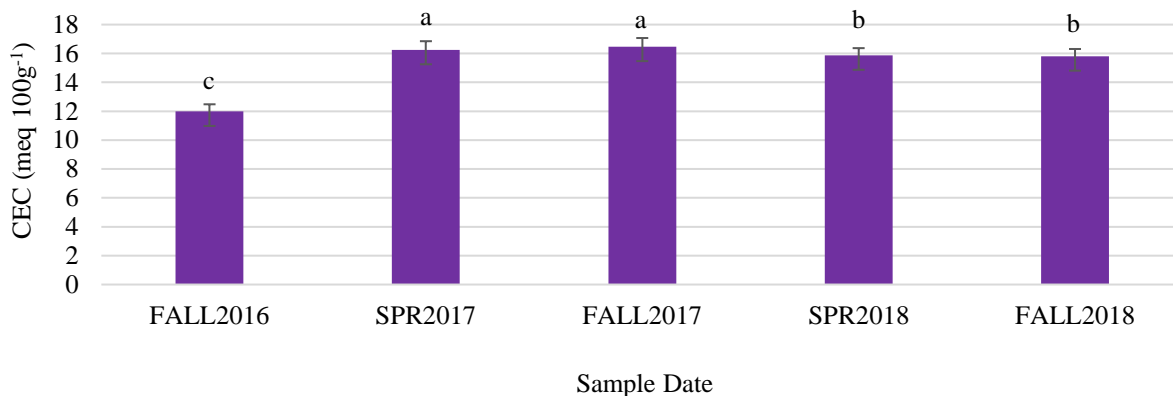


Figure 2.11. Cation exchange capacity (CEC) values across sample dates for Coushatta silt loam (CSL) and Moreland clay (MCl) soils. Bars with different superscripts are significantly different ( $\alpha=0.05$ )

Ketterlings et al. (2007) reported that clay soils tend to have higher CEC values than sandier soils, with higher values indicating more organic matter present and greater water holding capacity. Because of this, it is not surprising that there were differences in soil type

( $P < 0.0001$ ) for CEC with CSL at  $11.22 \text{ meq } 100\text{g}^{-1}$  and  $19.3 \text{ meq } 100 \text{ g}^{-1}$  for MCl. Cover crop seeding rate had a significant effect on CEC with values ranging from 14.98 to  $15.48 \text{ meq } 100 \text{ g}^{-1}$  across treatments ( $P = 0.017$ ). Results indicated crimson clover low rate (CCL), cereal rye low rate (RYEL), and cereal rye high rate (RYEH) had greater CEC than crimson clover medium rate (CCM) and tillage radish medium rate (RADM), but not for all other species and seeding rates ( $15.5, 15.5, 15.5, 15.1$ , and  $15.0 \text{ meq } 100 \text{ g}^{-1}$ , respectively, Figure 2.12). This may indicate that CEC is not influenced by specific cover crop species or seeding rates, but lower seeding rates can potentially provide comparable CEC values compared with medium and higher rates.

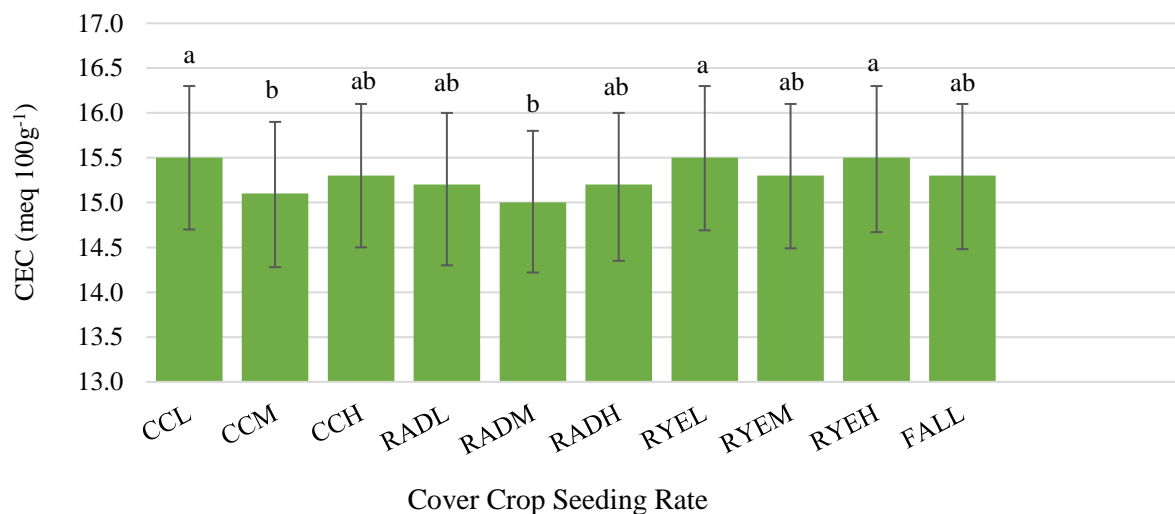


Figure 2.12. CEC values across cover crop seeding rates for Coughatta silt loam (CSL) and Moreland clay (MCl) soils. CC = crimson clover; RAD = tillage radish; RYE = cereal rye; L = low rate; M = medium rate; H = high rate. Bars with different superscripts are significantly different ( $\alpha=0.05$ ).

Cation exchange capacity increased after initial sample collection for CSL and MCI by 30% and 26% respectively ( $P < 0.0001$ , Figure 2.12). Values increased in the FALL2017 but decreased for SPR2018 and FALL2018 for both soil types. Because CEC is measured by the total number of cations a soil can hold (or its negative charge), this fluctuation could be attributed to specific cation nutrient levels ( $K^+$  and  $Ca^{+2}$ ) that were also reduced from the FALL2017.

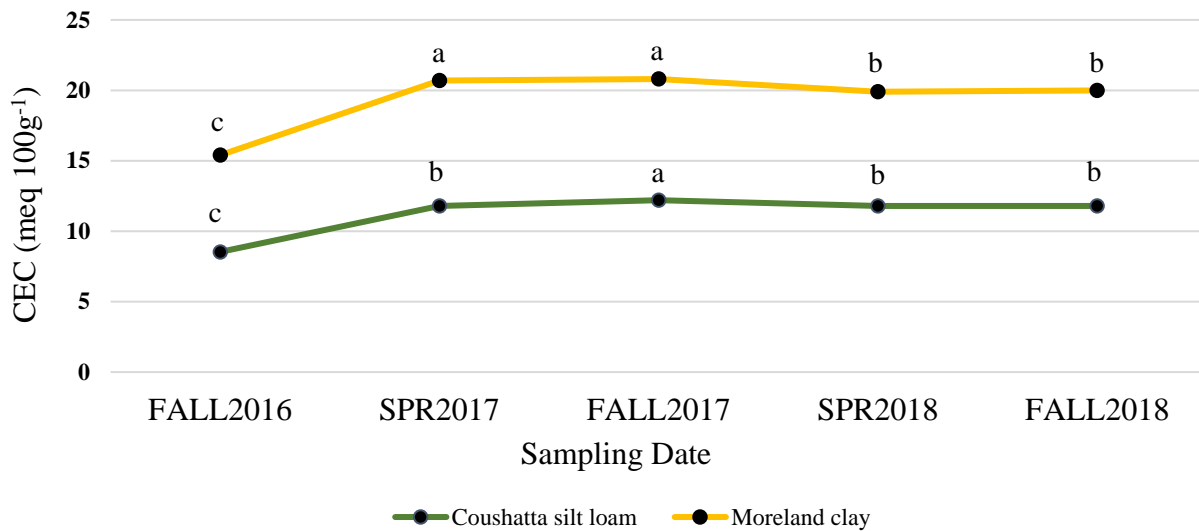


Figure 2.13. Cation exchange capacity (CEC) for Coushatta silt loam (CSL) and Moreland clay (MCI) soil across sample dates. Letters with different superscripts are significantly different ( $\alpha=0.05$ ) over time.

## Conclusion

Nutrient levels fluctuated throughout the study with significant effects for soil type, cover crop seeding rate, and sample date. The majority of nutrients had higher initial values then fluctuated over time with no particular sampling date correlating to all nutrient level changes. This would suggest the values are fluid and changed based on environmental conditions and specific crops utilizing the nutrients at that sampling time. Soil type had a significant effect on

nutrient levels, primarily based on soil texture differences between the heavy clay and silt loam soil, with specific nutrients having greater values in CSL versus MCI.

Inorganic nitrogen values for  $\text{NO}_3^-$ -N and  $\text{NH}_4^+$ -N increased and decreased throughout the course of this study with results indicating differences across sampling date. Because  $\text{NO}_3^-$ -N and  $\text{NH}_4^+$ -N are both very susceptible to losses through denitrification, volatilization, leaching, plant uptake, and used by microbial processes, consistent soil values are difficult to quantify. While  $\text{NO}_3^-$  levels peaked with initial sample date (SPR2017),  $\text{NH}_4^+$ -N levels peaked in the FALL2017, which could be attributed to environmental conditions during that timeframe.

Soil pH, CEC, and soil organic matter were impacted by sampling dates, soil type, and cover crop seeding rates, with the MCI having consistently higher organic matter concentrations than the CSL soil.

Previous research has shown that cover crops can improve the overall health of the soil, but continued implementation and success of the cover crop will ultimately determine the impact on chemical and physical properties long term. For this study, although changes were seen in soil nutrients and specific soil characteristics, more research is needed to verify that specific seeding rates of cover crops can have a more permanent impact on soil chemical properties.

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## CHAPTER 3. EFFECT OF COVER CROP SEEDING RATE AND SOIL TYPE ON COVER CROP BIOMASS AND WEED SUPPRESSION

### 3.1 Introduction

Cover crop seeding rates can have a significant impact on dry matter production, with growth rates and biomass differing among cover crop species and environmental factors (Paustian et al., 1997). While one goal of growing cover crops is to select a species and seeding rate that will produce maximum biomass and ground cover in the shortest amount of time, this can result in a secondary benefit of improving weed suppression for the following crop. Cover crop residues remaining on the soil surface can physically modify weed seed germination by altering the seed environment (changes in light availability, soil temperature, and soil moisture) and through other allelopathic interference (Creamer et al., 1996). Wang et al. (2010) found that in addition to accumulation of soil-nitrogen (N), higher plant biomass correlated to improved carbon sequestration and ground cover for erosion control, but can be influenced by species characteristics, growth rates, biomass accumulation rates and environmental factors.

Legumes, grasses, and brassicas each have different growth characteristics and biomass potential that may be beneficial for specific management goals. Though most winter cover crops in the southeastern U.S. are planted from September 1-November 30 (USDA, 2015), planting and termination dates may impact the amount of dry matter (DM) available for decomposition. Holste (2016), found that compared to cereal rye (*Secale cereale*), legumes produced the least amount of biomass (336 and 2353 kg ha<sup>-1</sup>, respectively), which correlated to legumes having the lowest total N per hectare, with cereal rye contributing the highest. Legumes are, however, known for having a low carbon to nitrogen (C:N) ratio, typically <16:1, (Wilson and Hargrove, 1985) which results in mineralization and N availability in a short period of time.

Cereal rye has a much higher C:N ratio of 35:1 at the boot stage (24:1 at stem elongation) but can produce up to 5043 kg ha<sup>-1</sup> biomass in optimum environmental conditions (Mirsky, 2019). Known for its excellent weed suppression, one Maryland study found cereal rye can reduce weed density by an average of 78% when cereal rye covered more than 90% of the soil surface (Teasdale et al., 1991). Another study found cereal rye residue reduced the emergence of several broadleaf weeds including common ragweed (*Abrosia artemisiifolia* L.) by 43% and redroot pigweed (*Amaranthus retroflexus* L.) by 95% (Putnam and DeFrank, 1983). Because cereal rye produces substantial biomass, many studies have focused on the effects of the nine chemicals considered allelochemicals and are believed to be toxic to many weed species (Barnes et al., 1987). Boyd et al. (2009) conducted a study to evaluate seeding rate and planting arrangement for cereal rye biomass and weed suppression. Seeding rates of 90, 180, and 270 kg ha<sup>-1</sup> did not affect total weed germination but did reduce weed biomass with increased seeding rate. This might indicate that seeding rates of particular species may influence cover crop biomass, which is directly related to weed control (Bybee-Finley et al., 2017), although factors such as planting date, management, and termination date must also be considered.

Tillage radish (*Raphanus sativus*) is also known for its allelopathic effects and weed suppression with fall weed competition being found as the dominant mechanism for early spring weed control (Lawley et al., 2012). Under favorable conditions, tillage radishes have the ability to extend root mass more than 91cm in 60 days and can create channels for infiltration, surface drainage, and soil warming. Biomass for both root and above-ground shoots can produce up to 7800 kg ha<sup>-1</sup>, which can provide substantial ground cover and residue for weed control (Gruver et al., 2016).

The majority of the 6.2 million hectares of cover crops in the U.S. are centralized in the Corn Belt (CTIC, 2012), with limited research being done to determine optimum cover crop seeding rates for the Mid-South region. Although most researchers agree that species, planting method, and seeding rate can all influence the amount of cover crop biomass produced, developing specific recommendations for soil type and geographic location is more difficult. Haramoto (2019) found that reducing the seeding rate of cereal rye from 112 kg ha<sup>-1</sup> to 34 kg ha<sup>-1</sup> under dry fall planting conditions resulted in increased biomass and ground cover, which also reduced weed biomass. Results from one study conducted across multiple latitudes in the northeastern U.S. indicated hairy vetch (*Vicia villosa*) produced maximum biomass at a lower seeding rate of 15-20 kg ha<sup>-1</sup> among all treatments (Mirsky et al., 2017). This data suggests lower seeding rates of specific species, under variable environmental conditions, can supply the necessary dry matter needed for maximum N accumulation and soil coverage. Sanju and Singh (1997) reported that variation in the biomass yield and N contribution of the cover crops from one place to another results from species adaptation to the site due to variation in soil and climatic conditions. Each species offers diverse benefits for fixing N, recycling nutrients, improving soil tilth, building soil organic matter and helping to break pest cycles (Wilson, 2019), so selection and economically viable seeding rates must be carefully considered.

Wang et al. (2010) concluded soil type significantly influenced biomass production and total N. Biomass production, soil N, and carbon (C) accumulation were greater in a fine, sandy soil than a loamy soil for specific species of cover crops, including purple vetch (*Vicia Americana*), triticale (*Triticosecale*), ryegrass (*Lolium*), bellbean (*Vicia faba*), and mustard (*Brassica*), but not for white clover (*Trifolium repens*). Delaney et al. (2016) reported a fine sandy loam produced more crimson clover biomass than a Compass loamy sand (9500 and 3401

kg ha<sup>-1</sup>, respectively), with similar results for tillage radish but not for cereal rye (3919, 2441, 6011, and 2892 kg ha<sup>-1</sup>, respectively). In contrast, some research suggests that fertile soils with some clay tend to produce higher biomass than infertile or very sandy soils (Gaskin et al., 2015), but research is limited in the evaluation of cover crop biomass in clay and silt soils. This information may indicate that soil type, in addition to other environmental conditions, could be a determinant factor in the success of cover crop management. One objective of this study was to determine if seeding rate and soil type (all other conditions equal) would influence cover crop biomass (with C and N concentrations), weed biomass, C:N ratio, and total N. It was hypothesized that the higher seeding rates of all species would produce the greatest biomass, total N, and have the greatest impact on weed suppression, with the heavier clay soil producing more biomass than a sandier, less fertile silt loam soil.

### 3.2 Materials and Methods

A two-year non-irrigated experiment was conducted at the LSU AgCenter Dean Lee Research and Extension Center, located 9.7 km south of Alexandria, Louisiana from 2016 to 2018. Three species of cover crops, cereal rye, tillage radish, and crimson clover (*Trifolium incarnatum*) were evaluated at low, medium, and high seeding rates, in addition to a control plot with no cover crops planted. Specific varieties included Daikon radish, AU Sunrise crimson clover, and Elbon rye, respectively. Cover crops were broadcast using seeding rates obtained from USDA-NRCS Cool Season Cover Crop Species & Planting Dates TX-PM-15-03 2015 and AL Extension ANR-2139 publications (Table 3.1).

Table 3.1. Seeding rate treatments for cover crop species in kg ha<sup>-1</sup> based on recommended broadcast rates

Cover Crop Species/Variety	Low Rate	Medium Rate	High Rate
	kg ha <sup>-1</sup>		
Daikon radish	7.9	11.2	14.6
AU Sunrise crimson clover	24.7	29.1	33.6
Elbon rye	62.8	98.6	134.5

Field locations included two areas with classified soil textures of clay and silt loam, specifically Moreland clay (MCI) and Coughatta silt loam (CSL) soils (Figure 3.1). These were located approximately 0.8 km apart on 0-1% slope.



Figure 3.1 Aerial view of (a) Moreland clay (Latitude, Longitude 31.178029 °N,-92.410545°W) and (b) Coughatta silt loam research plots (Latitude, Longitude 31.178047°N,-92.410498°W)

The Moreland clay (MCI) soil was classified as a very-fine, semiotic, thermic Oxyaquic Hapluderts and considered a very deep, somewhat poorly drained, permeable soil. In contrast, the Coughatta silt loam (CSL) classified as a fine-silty, mixed, superactive, thermic Fluventic Eutrudept soil that is very deep and well-drained (USDA, 2010). According to United States Department of Agriculture (USDA, 1997) both soil types are considered Prime Farmland and

suitable for growing crops. Previous crop rotations for each soil type included soybean (*Glycine max* L) and cotton (*Gossypium hirsutum*).

### 3.2.1 Experimental Design and Field Management

The experimental design was a randomized complete block of ten treatments with three replications, for a total of 30 plots per soil type. Plots consisted of four, 96.5 cm rows x 12.2m in length (~49 m<sup>2</sup>) with the two middle rows used for data collection. Nine seeding rate treatments were randomly assigned within each soil type, in addition to an untreated control plot (Figure 3.2). Initial field preparation included mechanically incorporating soybean residue from the previous crop as rows were conventionally prepared for cover crop planting using a Case International 235 Magnum tractor and cultivator equipment. According to initial soil test recommendations, P<sub>2</sub>O<sub>5</sub> was broadcast at a rate of 35.1 kg ha<sup>-1</sup> + K<sub>2</sub>O at 70.6 kg ha<sup>-1</sup> to each plot on October 1. Year two of the study followed the same protocol with an increase in fertilizer application rates of 45.4 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> + 90.8 kg ha<sup>-1</sup> of K<sub>2</sub>O.

110 CC L	109 RYE M	108 RAD H	107 CC M	106 RYE L	105 CC H	104 RAD M	103 FALL	102 RYE H	101 RAD L
210 RAD H	209 CC M	208 RYE M	207 RAD L	206 RYE H	205 CC L	204 CC H	203 RYE L	202 RAD M	201 FALL
310 CC M	309 RAD L	308 FALL	307 RAD M	306 RAD H	305 RYE H	304 CC H	303 RYE M	302 CC L	301 RYE L

Figure 3.2 Field experimental design with cover crop species (crimson clover [CC]; cereal rye [RYE]; tillage radish [RAD]; fallow [FALL]) and randomized seeding rates (low [L]; medium [M]; high [H]).

Seeds were broadcast onto prepared beds with an Earthway 3400 Ergonomic Hand-Held Broadcast spreader on October 17, 2016 and November 6, 2017, respectively. Planting dates were one-week post and prior to soil sample collections (for year one and two, respectively) due

to fall field preparation timing. Beds were immediately rolled with a culti-packer to ensure optimum seed-to-soil contact. Plots were not irrigated, and cover crops were planted into dry soil conditions after soybean harvest both years, which delayed emergence until approximately mid-November.

Approximately 155 and 141 days after planting (2017 and 2018, respectively), cover crops were chemically terminated on March 21 and March 18 with a herbicide mixture of glyphosate at  $0.95 \text{ L ha}^{-1}$  + 2, 4-D at  $0.95 \text{ L ha}^{-1}$  using a Case International 235 Magnum tractor and 8-row broadcast sprayer. Immediately prior to this, cover crop and weed biomass samples were collected by hand on March 20, 2017 and March 17, 2018. Using Gaskin, et al. (2015) sampling methods, two random samples were collected per plot using a  $0.09 \text{ m}^2$  PVC square. All plant material within the PVC square was clipped at ground level (including roots for tillage radish) and placed in a brown paper bag. Cover crops and total weed species were then separated, dried in forced air oven at  $105^\circ \text{ C}$  for 24 hours, then dry matter was weighed and recorded. Refrigerated, dried cover crop samples were sent to the LSU AgCenter Soil Testing and Plant Analysis Laboratory (STPAL) in Baton Rouge, LA and analyzed for percentage of carbon and nitrogen using a LECO CN Analyzer.

Calculations used to determine total cover crop and weed biomass ( $\text{kg ha}^{-1}$ ), total N ( $\text{kg ha}^{-1}$ ), and C:N ratios:

$$\text{Dry biomass (kg ha}^{-1}\text{)} = \text{fresh weight} - \text{moisture}$$

$$\text{Total N uptake} = \text{N\%} \times \text{dry weight biomass (kg ha}^{-1}\text{)}$$

$$\text{C:N ratio} = \text{\%C divided by \%N}$$

### 3.2.2. Statistical Analysis

Data were analyzed using the Mixed Model Analysis of Variance (%MMOV). Dependent variables included cover crop biomass, weed biomass, cover crop biomass carbon, cover crop biomass nitrogen, total nitrogen uptake, and C:N ratio, while independent variables were sampling date, cover crop seeding rate and soil type. Replication was considered a random effect. Cover crop biomass data were analyzed using Glimmix Procedure of SAS release 9.4, (SAS Institute Inc. 2013. SAS/STAT® 13.1 User's Guide. Cary, NC: SAS Institute Inc.) and means were separated using the Fisher's Least Significant Difference with the LSD option of the MEANS statement. An  $\alpha \leq 0.05$  was considered significantly different for all procedures. Correlation coefficients were calculated using the COOREL function of Microsoft Excel (2016).

### 3.3. Results and Discussion

#### *Cover Crop Biomass*

Cover crop dry matter accumulation plays a significant role in the amount of N content that is available, which is highly correlated with soil residual  $\text{NO}_3^-$ -N (Ruffo et al., 2004). Although research has supported soil type impacting plant growth and biomass in other studies, unexpectedly, cover crop biomass was not influenced by soil type during the duration of this project ( $P = 0.0927$ ). Coughatta silt loam (CSL) produced  $1245 \text{ kg ha}^{-1}$ , while MCI produced  $972 \text{ kg ha}^{-1}$  across spring of 2017 (SPR2017) and spring 2018 (SPR2018).

Cover crop biomass was 61% greater in SPR2017 compared to SPR2018 ( $P < 0.0001$ , Figure 3.3), which clearly shows the effect of variable environmental conditions on biomass. Late soybean harvest in October 2017 and drought conditions delayed cover crop planting by three weeks compared to 2016, reducing the number of days for accumulation before termination. Unusually cold temperatures and high precipitation during the winter of 2017-2018



also significantly reduced cover crop growth, with 47 cm of rain and 24 days of temperatures at or below 0° C from December to February (Figure 3.4). Cover crop biomass was also impacted by cover crop seeding rate ( $P < 0.0001$ ), with an interaction occurring for sample date by cover

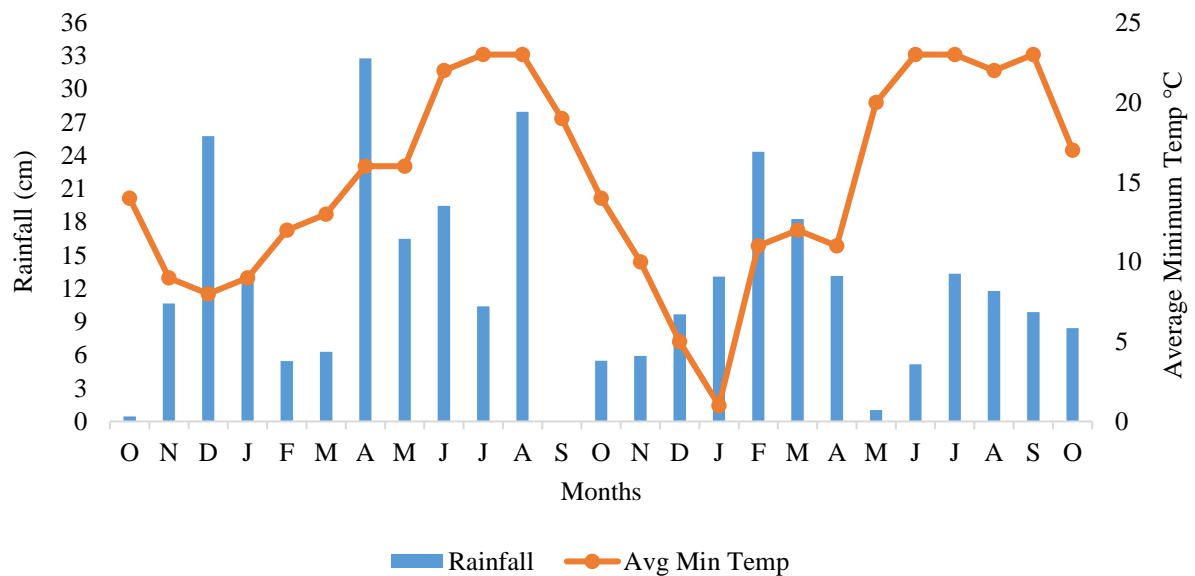


Figure 3.3. Average minimum monthly temperature and precipitation during 2016-2018 taken from Dean Lee Research Station weather station in Alexandria, LA

crop seeding rate ( $P = 0.0312$ ), but not for soil type by cover crop seeding rate ( $P = 0.0977$ ).

Cover crop biomass production, based on seeding rate, was species dependent. Surprisingly, not all high seeding rates produced the greatest amount of biomass within each species. There were no differences in biomass across the seeding rates of crimson clover (CC) and cereal rye (RYE), however, the low seeding rate of tillage radish (RADL) resulted in 56% higher biomass compared with the high seeding rate of tillage radish (RADH, Figure 3.4). Low seeding rate of tillage radish (RADL) was not different than the medium rate (RADM).

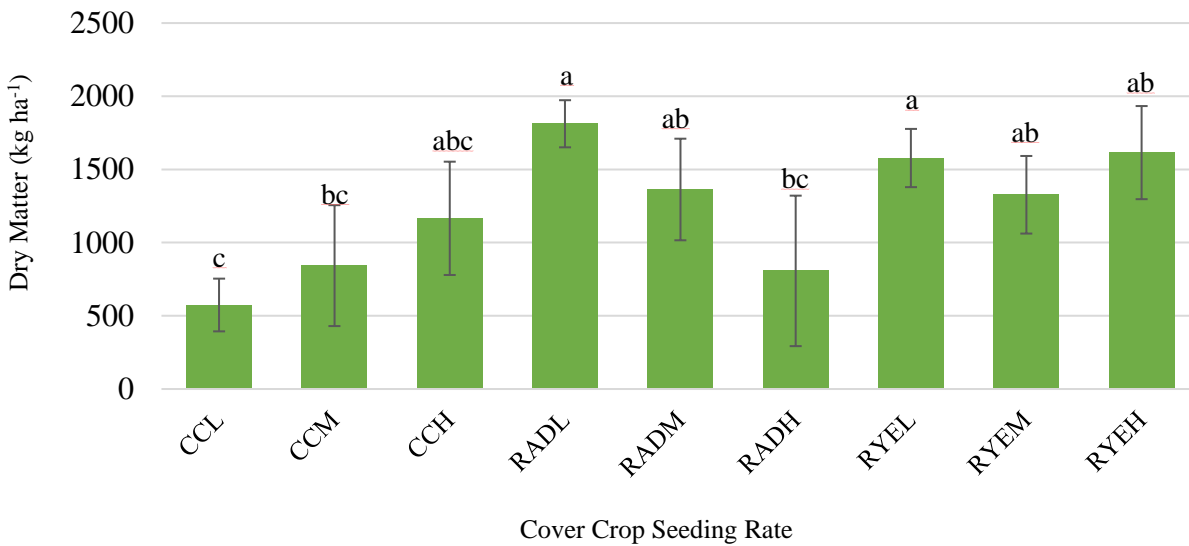


Figure 3.4. Cover crop biomass by cover crop seeding rate (kg ha<sup>-1</sup>). Crimson clover [CC]; cereal rye [RYE]; tillage radish [RAD]; fallow [FALL]) and randomized seeding rates (low [L]; medium [M]; high [H]). Bars with different superscripts are significantly different ( $\alpha=0.05$ ).

Weil and Kremen (2007) found that if conditions were favorable (optimum temperature and soil moisture), cover crops produced 3,000-6,000 kg ha<sup>-1</sup> of DM and nearly completely covered the ground before termination. Across two years, DM ranged from 574-1,812 kg ha<sup>-1</sup> across species and seeding rates, which is much lower than the reported potential accumulation. Dry soil conditions at planting both years, timing of rainfall, and temperature fluctuations appeared to have impacted potential growth and accumulation over the course of this study. High seeding rates of crimson clover produced the greatest amount of DM at 1166 kg ha<sup>-1</sup> but was not significantly different from low and medium rates. Cereal rye averaged 1507 kg ha<sup>-1</sup> across all seeding rates and produced as much or more biomass as the high seeding rates of crimson clover and tillage radish.

Sangoi (2001) reported that the use of high populations heightens interplant competition for light, water, and nutrients and may be detrimental to yield. These results indicate that without

the additional interspecies competition, certain cover crop species may have the ability to increase plant biomass accumulation at low-medium seeding rates under favorable conditions.

#### *Biomass Carbon, Biomass Nitrogen, Total Biomass Nitrogen and C:N Ratio*

Cover crops can contribute a significant amount of fertility to the succeeding crop through biomass C and N inputs. Total biomass C concentration results indicated differences based on seeding rate, with interactions occurring between sample date and soil type and sample date by seeding rate by soil type ( $P < 0.0001$  for all differences). High seeding rate of crimson clover was 44% higher in C than CCM, but not higher than CCL (Figure 3.5). There were no differences in C concentration within species for tillage radish or cereal rye across seeding rates. Interactions occurring for sample date by soil type and sample date by seeding rate

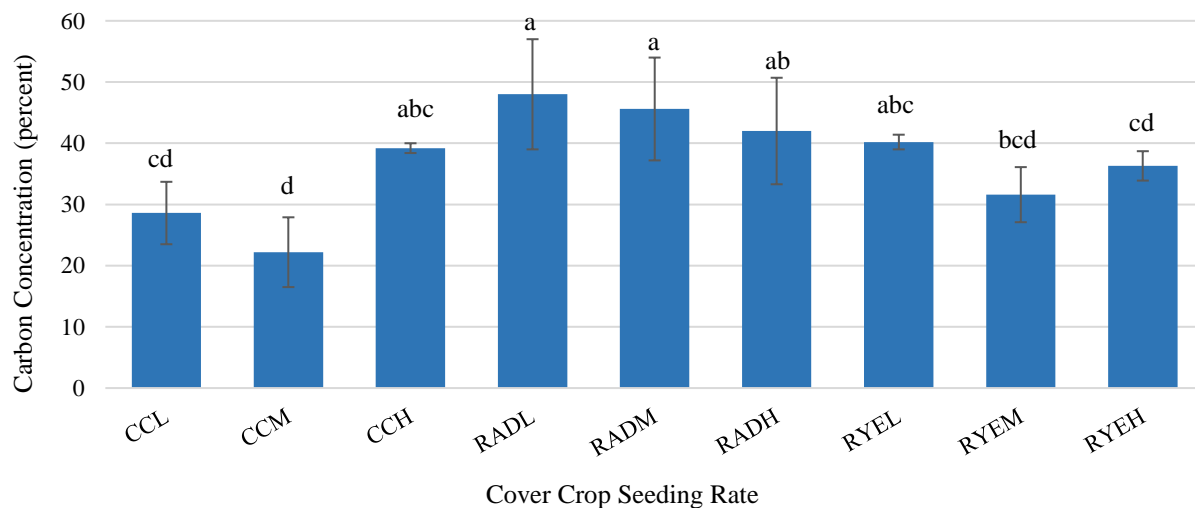


Figure 3.5. Carbon concentrations across cover crop seeding rates. Crimson clover [CC]; cereal rye [RYE]; tillage radish [RAD]; fallow [FALL]) and randomized seeding rates (low [L]; medium [M]; high [H]). Bars with different superscripts are significantly different ( $\alpha = 0.05$ ).

by soil type indicated that environmental conditions that varied from 2017 to 2018 had a significant impact on cover crop biomass, and ultimately, C concentrations within cover crop species (Appendix).

Biomass N concentration differed by sample date and cover crop seeding rate ( $P = 0.0002$  and  $<0.0001$ , respectively), with an interaction between sample date by soil type ( $P = 0.0210$ ). Concentrations were reduced from 1.94% in 2017 to 1.25% in 2018, which resulted in a 36% decrease. Cover crop seeding rates also affected biomass N accumulation, with CCH having the greatest N concentration at 2.2%, and being greater than RYEM at 1.3%, but not different than all other cover crop seeding rates (Figure 3.6).

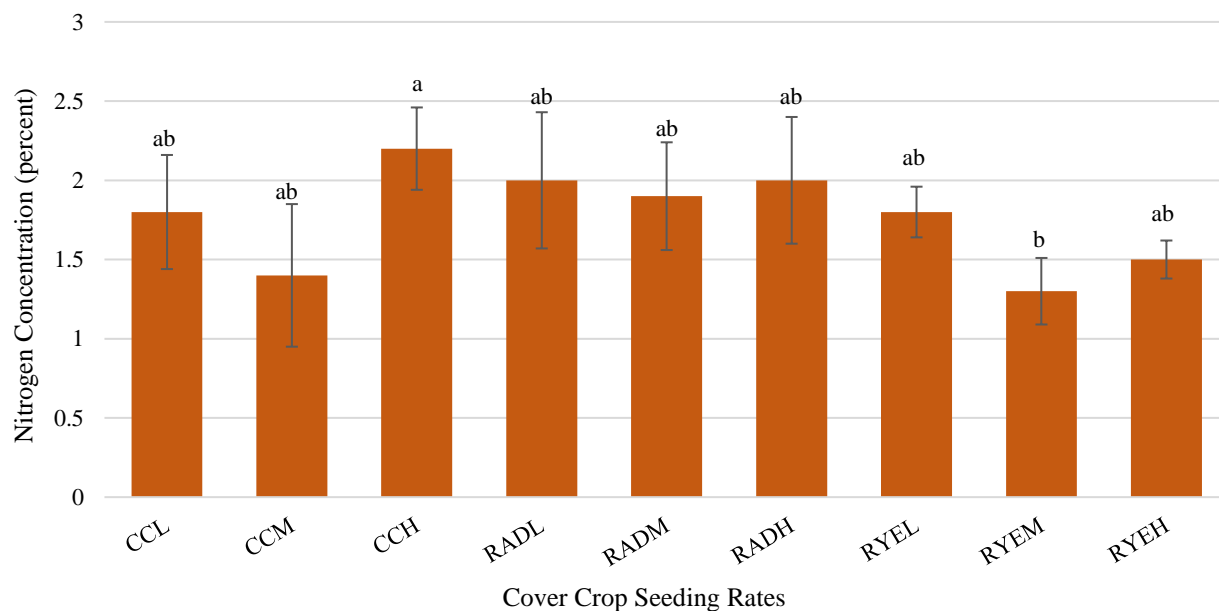


Figure 3.6. Nitrogen concentrations across cover crop seeding rates. Crimson clover [CC]; cereal rye [RYE]; tillage radish [RAD]; fallow [FALL]) and randomized seeding rates (low [L]; medium [M]; high [H]). Bars with different superscripts are significantly different ( $\alpha = 0.05$ ).

Sample date by soil type interaction results indicated differences in the MCI soil between SPR2017 and SPR2018, but not for CSL (Table 3.2).

Plant available N from cover crops are highly dependent on the growth stage of the plant when terminated, and concentrations peak when legumes are at budding stage, cereals are tillering, and brassicas are at flowering stage (Sullivan and Andrews, 2012). Because all species in this study were terminated at the same time, they were not necessarily at the “peak” termination stage due to reductions in days from 155 to 141 from 2017 to 2018, thereby reducing time for N accumulation.

Table 3.2 Soil type by sample date interaction for percent biomass nitrogen concentration (standard errors are in parenthesis).

Soil Type	Biomass Nitrogen	
	%	
	2017	2018
Moreland clay	2.13(0.242) a <sup>†</sup>	1.00(0.133) b
Coushatta silt loam	1.76(0.189) a	1.48(0.164) a
<i>P value</i>	0.0210	

<sup>†</sup>Different letters denote differences across sample dates by soil type ( $\alpha=0.05$ )

### *Total Biomass Nitrogen*

Because N is typically the most limiting nutrient in crop production (and also has the most potential for environmental impact from losses), estimating the amount of available N from cover crops can be very beneficial in cover crop management (Taylor and Cook, 2018). Cover crop biomass N is multiplied by dry biomass (kg) to provide an estimate of the total biomass-N provided by the cover crop on a per hectare basis. Results for total biomass N ( $\text{kg ha}^{-1}$ ) was similar to results for cover crop biomass N, with differences for sample date ( $P < 0.0001$ ), cover crop seeding rate ( $P = 0.0034$ ), and interaction for sample date by cover crop seeding rate ( $P = 0.0415$ ). There was a 72% decrease from SPR2017 to SPR2018 ( $38.9$  and  $10.9 \text{ kg ha}^{-1}$ , respectively).

Clark (2007) reported the amount of nitrogen captured is mainly related to biomass accumulation and the amount of N available in the soil profile, which supports the correlation of reduced biomass from 2017 to 2018 in this study. Total N content for RADL was greater than all species and seeding rates, with the exception of RADM (52.8 and 36.3 kg ha<sup>-1</sup>, Figure 3.7), which indicates the potential for tillage radish at lower seeding rates to provide equal or greater N to the soil profile.

Clark (2007) reports that specific cover crops may provide substantial N to the cropping system, including up to 56 kg N ha<sup>-1</sup> for crimson clover, 191 kg N ha<sup>-1</sup> for tillage radish, and 168 kg N ha<sup>-1</sup> for cereal rye (Clark, 2007). Time of planting and termination of the cover crop affects the percentage of aboveground N uptake, and ultimately, total N that is available (Lal, 2015). Results from this study indicate that cover crop growth and biomass may have been impacted by late germination and early termination, thereby reducing the amount of time for N uptake and overall total biomass N.

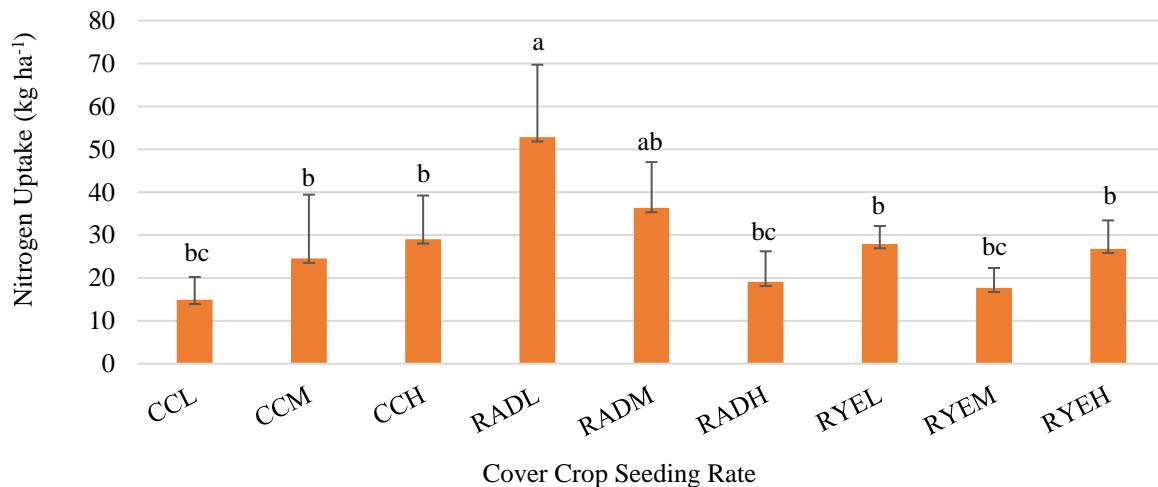


Figure 3.7. Total nitrogen uptake across cover crop seeding rates (kg ha<sup>-1</sup>). Crimson clover [CC]; cereal rye [RYE]; tillage radish [RAD]; fallow [FALL]) and randomized seeding rates (low [L]; medium [M]; high [H]). Bars with different superscripts are significantly different ( $\alpha=0.05$ ).

### C:N Ratio

Optimum C:N ratio for most soil systems is <24:1, with ratios above this causing N immobilization and ratios below initiating mineralization and N availability (USDA, 2011). All species included in this study are known to have C:N ratios of 13-40:1 for plants that have not reached maturity (USDA, 2011), which makes them readily decomposable and useable by both microbes and available to the following cash crop in a short period of time (Justes et al., 1999; UC SAREP, 2019). Cereal rye and crimson clover biomass samples were collected when plants were still in vegetative growth stage, while tillage radish roots and top growth were collected after flowering. Results indicated differences by sample date ( $P = 0.0018$ ), cover crop seeding rate ( $P < 0.0001$ , Figure 3.8), and interactions for cover crop seeding rate by soil type ( $P = 0.0087$ , Appendix) and sample date by cover crop seeding rate by soil type ( $P < 0.0001$ , Appendix).

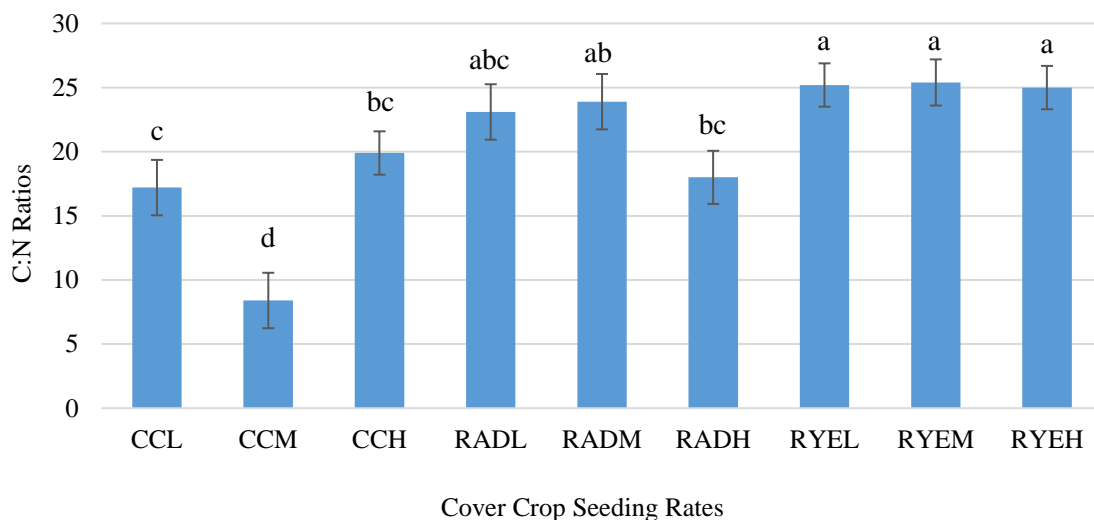


Figure 3.8. Carbon nitrogen ratios across cover crop seeding rates for Coughatta silt loam and Moreland clay soils (Crimson clover [CC]; cereal rye [RYE]; tillage radish [RAD]; fallow [FALL]) and randomized seeding rates (low [L]; medium [M]; high [H]). Bars with different superscripts are significantly different ( $\alpha = 0.05$ ).

The mean C:N ratio across all cover crop seeding rates for spring 2017 was 18:1, where spring 2018 was 25:1. At the time of sample collection, all cover crop seeding rates had C:N ratios ranging from 8:1 to 25:1, which would suggest that all cover crop N from these treatments would be mineralized and no immobilization occurred based on C:N ratios for any of the species. This would be advantageous for subsequent crops that are early season high-N consumers like corn (*Zea mays*) and cotton (*Gossypium hirsutum*) but may not significantly contribute to the soil N bank for nitrogen needed later in the season.

#### *Weed Biomass*

The use of cover crops for weed suppression in subsequent cash crops is an integral part of cover crop management. Although weed biomass was not affected by sample date ( $P = 0.4634$ ), overall weed DM increased from 452 kg ha<sup>-1</sup> in SPR2017 to 596 kg ha<sup>-1</sup> in 2018, which was a 24% increase from year one to year two. Cover crop seeding rate impacted weed biomass ( $P = 0.0232$ ), however, soil type did not ( $P = 0.608$ ). Within species, there were no differences in biomass for cover crop seeding rate, however, CCH biomass was greater than all seeding rates of RYE, and medium and high rates of RAD (Figure 3.9). As expected, FALL weed biomass was greater than medium and high rates of RAD, and all rates of RYE. All seeding rates of crimson clover produced the same weed biomass as the FALL treatment, which indicates that clover biomass may not have reached maximum ground cover by termination date.



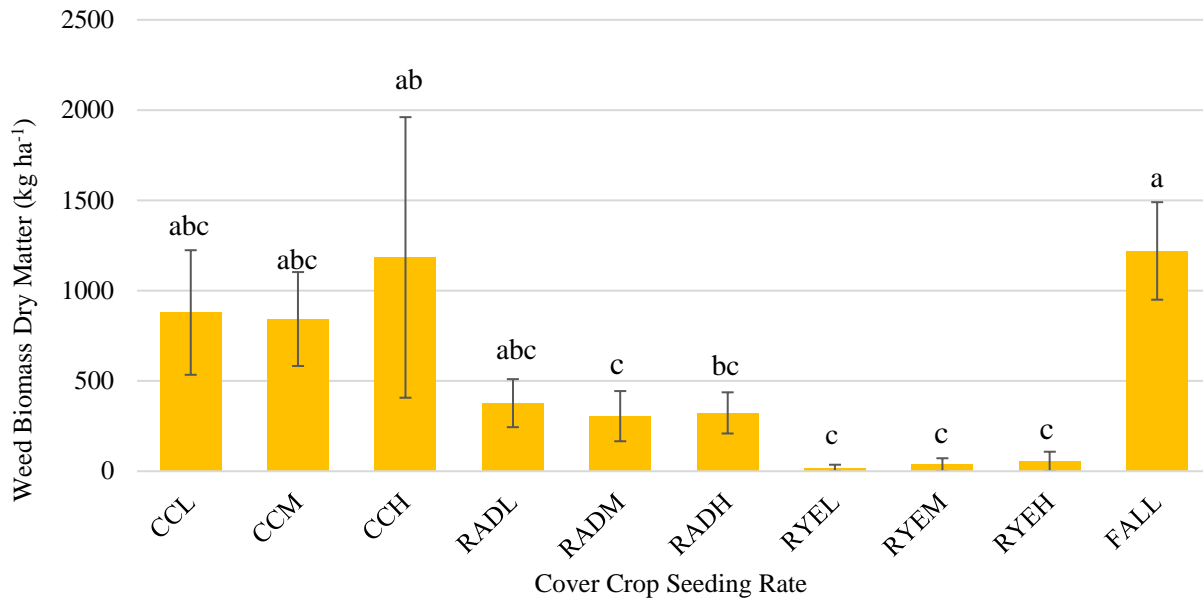


Figure 3.9. Weed biomass by cover crop seeding rate (kg ha<sup>-1</sup>). CC = crimson clover; RAD = tillage radish; RYE = cereal rye; L = low seeding rate; M = medium seeding rate; H = high seeding rate. Bars with different superscripts are significantly different ( $\alpha=0.05$ )

Cereal rye and tillage radish, regardless of seeding rate, reduced weed biomass more than all seeding rates of crimson clover, which may be an indication of significant weed suppression with these species of cover crops.

In evaluating biomass differences, it was determined that there was a moderately negative correlation ( $R^2 = 0.5234$ ) between cover crop biomass and subsequent weed biomass (Figure 3.10). Across cover crop seeding rates, as cover crop biomass decreased, weed biomass increased.

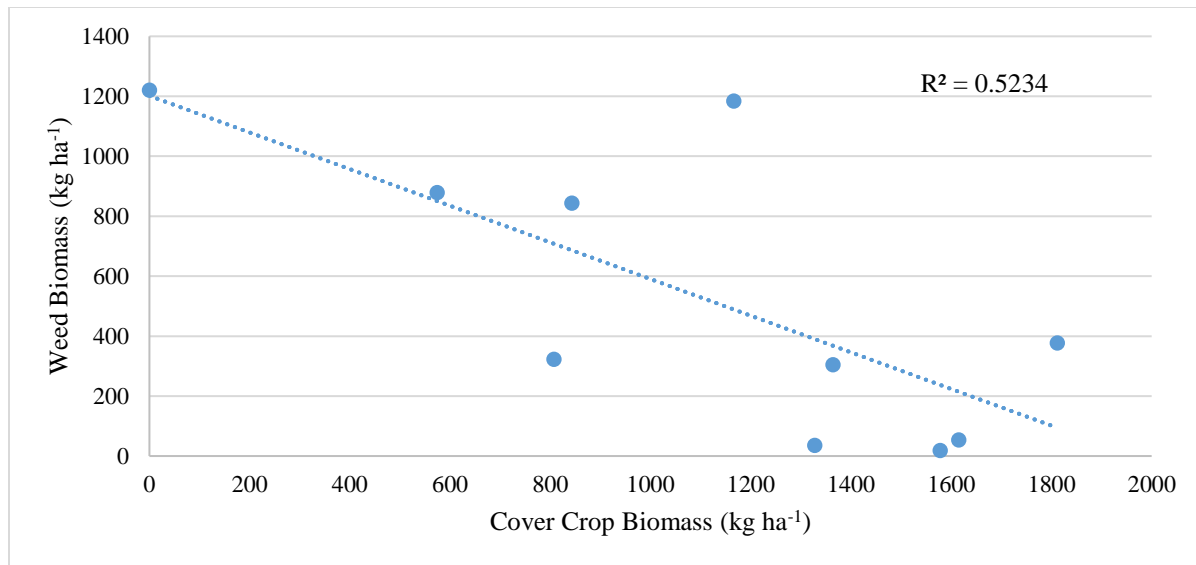


Figure 3.10. Correlation between cover crop biomass and weed biomass across cover crop seeding rates.

This supports research conducted by Ryan et al. (2011) that even though increasing seeding rate may not increase cover crop biomass, it can effectively reduce weed biomass and ground cover in the early spring, which can influence weed biomass later in the growing season. Identification of cover crops (and seeding rates) that can either produce weed suppressive biomass or that have outsized suppressive effects, either via allelopathic or other types (Liebman and Davis, 2000), would prove valuable in management decisions.

### 3.4. Conclusion

Environmental conditions had a significant impact on winter cover crop biomass, which caused reductions in biomass from 2017 to 2018. Even though rainfall accumulation for the cover crop growing seasons (October – April) was not out the normal range (94.7 cm and 85.1 cm for 2017 and 2018, respectively), the timing of heavy precipitation with below freezing temperatures reduced vegetative growth and biomass, in some cases, to 10-15% of a normal stand in 2018. Interestingly, soil type had no effect on cover crop biomass, which may reduce the

number of variables a producer must evaluate when deciding which species to plant. Lower seeding rates of tillage radish had equal biomass to RADM, and out-yielded RADH. No differences were measured in crimson clover and cereal rye, which indicated differences were species dependent. Weed biomass was not affected by sample date or soil type but results indicated as cover crop biomass increased, weed biomass decreased. This supports the goal of selecting a species and seeding rate that will provide sufficient biomass and ground cover to help suppress weeds for early season weed-control. Crimson clover, which produced lower biomass, resulted in the greatest weed biomass, while weed biomass in cereal rye was the lowest.

Nitrogen uptake was reduced from 2017 to 2018 as cover crop biomass was reduced during this timeframe. High seeding rates of crimson clover had greater biomass N concentrations than RYEM. This would indicate N concentrations may not have reached maximum level for certain species when terminating in mid to late March. Total N was similar to biomass N concentration results with RADL providing greater total N than all other species and seeding rates except RADM. Although tillage radish provided the most total N, C:N ratios were higher for low and medium seeding rates, which suggests that they may be less favorable for decomposition and release if N is required in a short period of time. Carbon to nitrogen ratios were lower for all seeding rates of crimson clover compared to other species and seeding rates, with all seeding rates of cereal rye being the highest. When evaluating winter cover species and seeding rates, producers may be able to select specific species at lower, more economical rates, but N mineralization and potential immobilization must be accounted for.

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## **CHAPTER 4. EVALUATION OF COVER CROP SEEDING RATE AND SOIL TYPE ON SOYBEAN PRODUCTION WITH POTENTIAL ECONOMIC IMPACTS**

### **4.1 Introduction**

Integrating winter cover crops into agricultural production systems is not a new practice. The use of alfalfa (*Medicago sativa*), clovers (*Trifolium*), and lupine (*Lupinus*) increased wheat (*Triticum aestivum*) yields date as far back as 29 B.C.E. (Fulk, 2014). The species of cover crop selected depends on the objectives of the grower, with each having its own characteristics that make them advantageous. Heavy nitrogen (N)-dependent crops like field corn (*Zea mays*) and cotton (*Gossypium hirsutum*) may benefit from a legume that can fix atmospheric-N or a grass species that can scavenge excess soil N, while reducing nitrate leaching. Brassicas are also scavengers and are known to help alleviate compacted soils, especially in drought-prone regions (Williams and Weil, 2004). Cash crops like soybeans (*Glycine max* L.) are a summer legume that are able to fix atmospheric-N, so winter covers are not typically planted in a soybean production system for the purpose of N fixation. Soybean rotation systems, however, may benefit from increased organic matter, improved water aggregate stability, and soil penetration resistance (Villamil et al., 2006).

Although it has been well documented that winter cover crops provide vegetative cover in erosion-prone areas in the winter (Frankenberger and Abdelmagid, 1985; Smith et al., 1987) and improve physical, chemical, and biological soil properties (Hoyt and Hargrove, 1986; Power and Doran, 1988; Vigil and Kisse, 1991), questions regarding impacts on crop yield still remain. Williams and Weil (2004) found soybean yields were significantly greater following a forage radish (*Raphanus sativus* var. *oleiformis*) and cereal rye (*Secale cereale*) mixture, mainly due to the conservation of water early in the season and reduction of soil resistance with root channels

from the radishes. A study conducted across five locations in Iowa over four years indicated soybean grain yield was not affected positively or negatively by the cereal rye cover crop planted after corn, but corn yield was 5% lower compared to no rye cover crop (Sawyer et al., 2017). Delaney et al. (2016) reported greater soybean plant population counts in no-cover crop treatments compared with cover crop treatments in a fine-sandy loam soil but no differences in a Compass loamy sand. Results from that study concluded all cover crop treatments increased soybean yield by 188.3-627.7 kg ha<sup>-1</sup> in a fine, sandy loam soil. On-farm comparisons in Maryland, Ohio, Pennsylvania, and Illinois reported significant increases in corn and soybean yields following tillage radishes compared to fallow or other cover crop species (Gruver et al., 2012), primarily due to early-season available soil-N. Because research shows inconsistent crop growth and yield responses to cover crops across soil types, species, seeding rates, and cropping systems, more data needs to be collected to address the potential challenges of these variables.

Even with potential yield response challenges, producers across the country increased cover crop acreage nearly 60% from 2014 to 2016 (SARE, 2017), with acreage expected to continue to increase. A wide-spread implementation may still be hindered due to the risk and inconsistent return on investments. Evaluating cover crop cost/benefit ratios are difficult, mainly due to upfront costs with management changes and hard-to-quantify benefits such as soil health improvements. Additional inputs that may prevent implementation include additional equipment, seed cost and planting, and pesticide applications, which can add a significant cost to production. Some benefits may be realized in a short period of time including reduced erosion and weed pressure, however increased soil organic matter and field productivity (increased cash crop yield) may take several years. Myers et al. (2018) reports that it can take three or more years for cover crops to pay off if no incentive payments are obtained and no special circumstances exist. Some



studies show that cover crops become more profitable as the price of N increases (Clark, 2007), mainly due to reduced fertilizer applications with cover crop implementation. One objective of this study was to evaluate costs associated with various species and seeding rates, in addition to potential financial net returns. Because N is not typically applied to soybeans, cost-savings for reduced fertilizer applications was not included in the analysis. Additionally, an objective of this study was to determine the impact of cover crop seeding rates and soil type on soybean growth and grain yield. It is hypothesized that high seeding rates of all species planted will increase soybean growth but may not have a significant yield impact.

## 4.2. Materials and Methods

### 4.2.1 Site Description

A two-year non-irrigated experiment was conducted at the LSU AgCenter Dean Lee Research and Extension Center, located 9.7 km south of Alexandria, Louisiana from 2016 to 2018. Three species of cover crops, Elbon rye, Daikon radish (*Raphanus sativus* L.), and AU Sunrise crimson clover (*Trifolium incarnatum*) were evaluated at low, medium, and high seeding rates, in addition to a control plot with no cover crops planted. Cover crops were broadcast using seeding rates obtained from USDA-NRCS Cool Season Cover Crop Species & Planting Dates TX-PM-15-03 2015 and AL Extension ANR-2139 publications (Table 4.1).

Table 4.1. Seeding rate treatments for cover crop species in kg ha<sup>-1</sup> based on recommended broadcast rates

Cover Crop Species/Variety	Low Rate	Medium Rate	High Rate
		kg ha <sup>-1</sup>	
Daikon radish	7.9	11.2	14.6
AU Sunrise crimson clover	24.7	29.1	33.6
Elbon rye	62.8	98.6	134.5

Field locations included two areas with classified soil textures of clay and silt loam, specifically Moreland clay (MCI) and Coughatta silt loam (CSL) soils (Figure 4.1). These were located approximately 0.8 km apart on 0-1% slope.



Figure 4.1 Aerial view of (a) Moreland clay (Latitude, Longitude 31.178029 °N,-92.410545°W) and (b) Coughatta silt loam research plots (Latitude, Longitude 31.178047°N,-92.410498°W)

The Moreland clay soil was classified as a very-fine, semiotic, thermic Oxyaquic Hapluderts and considered a very deep, somewhat poorly drained, permeable soil (USDA, 2010). In contrast, the Coughatta silt loam classified as a fine-silty, mixed, superactive, thermic Fluventic Eutrudept soil that is very deep and well-drained. According to United States Department of Agriculture (USDA, 1997) both soil types are considered Prime Farmland and suitable for growing crops. Previous crop rotations for each soil type included soybean and cotton (*Gossypium hirsutum*).

#### 4.2.2 Experimental Design and Field Management

The experimental design was a randomized complete block of ten treatments with three replications, for a total of 30 plots per soil type. Plots consisted of four, 96.5 cm rows x 12.2m in length ( $\sim 49 \text{ m}^2$ ) with the two middle rows used for data collection. Nine seeding rate treatments were randomly assigned within each soil type, in addition to an untreated control plot (Figure 4.2). Initial field preparation included mechanically incorporating soybean residue from the previous crop as rows were conventionally prepared for cover crop planting using a Case International 235 Magnum tractor and cultivator equipment. According to initial soil test recommendations,  $\text{P}_2\text{O}_5$  was broadcast at a rate of  $35.1 \text{ kg ha}^{-1}$  +  $\text{K}_2\text{O}$  at  $70.6 \text{ kg ha}^{-1}$  to each plot on October 1. Year two of the study followed the same protocol with an increase in fertilizer application rates of  $45.4 \text{ kg ha}^{-1} \text{ P}_2\text{O}_5$  +  $90.8 \text{ kg ha}^{-1} \text{ K}_2\text{O}$ .

110 CC L	109 RYE M	108 RAD H	107 CC M	106 RYE L	105 CC H	104 RAD M	103 FALL	102 RYE H	101 RAD L
210 RAD H	209 CC M	208 RYE M	207 RAD L	206 RYE H	205 CC L	204 CC H	203 RYE L	202 RAD M	201 FALL
310 CC M	309 RAD L	308 FALL	307 RAD M	306 RAD H	305 RYE H	304 CC H	303 RYE M	302 CC L	301 RYE L

Figure 4.2 Field experimental design with cover crop species (crimson clover [CC]; cereal rye [RYE]; tillage radish [RAD]; fallow [FALL]) and randomized seeding rates (low [L]; medium [M]; high [H]).

Seeds were broadcast onto prepared beds with an Earthway 3400 Ergonomic Hand-Held Broadcast spreader on October 17, 2016 and November 6, 2017, respectively. Planting dates were one-week post and prior to soil sample collections (for year one and two, respectively) due to fall field preparation timing. Beds were immediately rolled with a culti-packer to ensure optimum seed-to-soil contact. Plots were not irrigated, and cover crops were planted into dry soil

conditions after soybean harvest both years, which delayed emergence until approximately mid-November.

#### *Year One: 2017*

Approximately 155 after planting, cover crops were chemically terminated on March 21, 2017 with a herbicide mixture of glyphosate at  $0.95 \text{ L ha}^{-1} + 2, 4\text{-D}$  at  $0.95 \text{ L ha}^{-1}$  using a Case International 235 Magnum tractor and 8-row broadcast sprayer. According to Copes et al. (2018), a spring burn down herbicide should be applied 4-6 weeks prior to planting to allow adequate plant decomposition and reduce winter pest carryover potential. Subsequently, a 4.9 maturity Liberty Link® soybean (Hornbeck HBK 4953 LL) was planted on May 10, 2017 in both MCI and CSL soils at a seeding rate of  $325,040 \text{ seed ha}^{-1}$ . Field operations throughout the season included five herbicide applications, one fungicide, and one insecticide application (Table 4.2). Agronomic data collected and analyzed included plant population, plant height, and grain yield. Five plant population counts were collected per plot at the V6 growth stage using a one-meter stick and plants were counted per meter of row and recorded. Plant heights were also taken at the R8 growth stage, immediately prior to harvest, using a meter stick. Soybeans from the middle two rows were harvested on October 5, 2017 with Massey-Ferguson 8XP plot combine and dry weight and moisture were recorded. The yield was calculated ( $\text{kg ha}^{-1}$ ) and adjusted to 13% moisture.

#### *Year Two: 2018*

The following year, to accommodate an optimum soybean planting date, cover crops were chemically terminated after only 141 days on March 18, 2018 with a combination of glyphosate at  $0.95 \text{ L ha}^{-1} + 2, 4\text{-D}$  at  $0.95 \text{ L ha}^{-1}$ . A 5.1 maturity Roundup-Ready® soybean (Asgrow AG51X8 RR) was planted on May 4<sup>th</sup> at a seeding rate of  $325,040 \text{ seed ha}^{-1}$ . Droughty

conditions reduced soybean emergence in the MCI soil to approximately 10-15% of acceptable plant population (Spivey et al., 2018) and was chemically terminated on June 7. The plot was replanted the same day at a seeding rate of 325,040 seed ha<sup>-1</sup>. Six herbicide applications were made (including a termination application before re-plant) and three insecticide applications for 2018. Soybean plant populations and heights were again recorded at the V6 and R8 growth stages. The CSL plots were harvested on October 3rd with a Massey-Ferguson 8XP plot combine and dry weight and moisture were recorded. Due to re-planting, soybeans in the MCI plot were harvested approximately three weeks later, on October 24th. Grain weight and moisture were recorded, and yield was adjusted to 13% moisture.

Table 4.2. Field and management practices for soybean growing seasons (2017-2018)

Date	2017 Management Practice	*Date	2018 Management Practice
	Silt Loam/Clay		Silt Loam/Clay
5-10	Planted HBK 4953 LL @ 50,100 seed ha <sup>-1</sup> w/JD 1700 Max-emerge 8 row planter	5-4	Planted AG51X8 @ 50,100 seed ha <sup>-1</sup> w/JD 1700 Max-emerge 8 row planter
5-10	Applied Panther herbicide @ 146 ml ha <sup>-1</sup>	5-4	Applied Panther herbicide @ 146 ml ha <sup>-1</sup>
6-9	Applied Liberty herbicide @ 2339 ml ha <sup>-1</sup> + Medal II herbicide @ 1462 ml ha <sup>-1</sup>	5-18/6-7	Applied ENVY Intense herbicide @ 2339 ml ha <sup>-1</sup> / Replanted AG51X* @50,100 seed/ha <sup>-1</sup>
7-7	Applied Liberty herbicide @ 2339 ml ha <sup>-1</sup>	6-8/8-16	Applied Medal II herbicide @ 1462 ml ha <sup>-1</sup> / Applied Belt insecticide @ 146 ml ha <sup>-1</sup>
7-19	Applied Affiance fungicide @ 877 ml ha <sup>-1</sup>	6-9/8-27	Applied ENVY Intense herbicide @ 2339 ml ha <sup>-1</sup> /Applied Leverage insecticide @ 292 ml ha <sup>-1</sup> + Prevathon insecticide @ 1169 ml ha <sup>-1</sup>

Table Continued.

2017		2018	
Date	Management Practice Silt Loam/Clay	*Date	Management Practice Silt Loam/Clay
8-21	Applied Livid 97 insecticide @ 1.1 kg ha <sup>-1</sup> + Reveal insecticide @ 468 ml ha <sup>-1</sup>	8-16	Applied Belt insecticide @ 146 ml ha <sup>-1</sup>
9-15	Applied Livid 97 insecticide @ 1.1 kg ha <sup>-1</sup>	8-27	Applied Leverage insecticide @ 292 ml ha <sup>-1</sup>
9-26	Applied Devour herbicide @ 775 ml ha <sup>-1</sup>	9-14/10-7	Applied Devour herbicide @ 775 ml ha <sup>-1</sup>
10-5	Harvested soybeans	10-3/10-24	Harvested soybeans

\*Dates for applications in 2018 were different for each soil type due to replanting of MCI plot

### 4.2.3 Economic Evaluation

Evaluation of the financial impact of planting cover crops into a soybean production system was completed using a Cover Crops Decision Making Tool that used a cover crop production cost estimator developed by the LSU AgCenter (Adusumilli et al., 2018). This Microsoft EXCEL program utilizes specific species, seeding rates, planting methods, fertilization, chemical applications, and labor costs in the calculation (Table 4.3). This information was used in estimating potential financial net returns based on soybean yields for each plot, with average direct and indirect costs of production and a projected market price of \$351.27 per metric ton of soybeans (USDA, 2019).

Table 4.3. Cover crop production costs by species and seeding rate

Cover Crop	Broadcast Seeding Rate (kg ha <sup>-1</sup> )	Production Cost (Dollar ha <sup>-1</sup> )
AU Sunrise crimson clover	24.7 (L)†	\$179.02
	29.1 (M)	\$193.84
	33.6 (H)	\$208.67
Daikon radish	7.9 (L)	\$123.45
	11.2 (M)	\$134.57
	14.6 (H)	\$145.68
Elbon cereal rye	62.8 (L)	\$145.93
	98.6 (M)	\$173.59
	134.5 (H)	\$201.26
Fallow	0	\$20.72 (burndown only)

†L= low seeding rate; M= medium seeding rate; H = high seeding rate

#### 4.2.4 Statistical Analysis

Data were analyzed using the Mixed Model Analysis of Variance (%MMOV). Dependent variables included cover soybean plant heights, soybean plant population, and soybean grain yield, while independent variables were sampling date, cover crop seeding rate, and soil type. Replication was considered a random effect. Soybean data were analyzed using Glimmix Procedure of SAS release 9.4, (SAS Institute Inc. 2013. SAS/STAT® 13.1 User's Guide. Cary, NC: SAS Institute Inc.) and means were separated using the Fisher's Least Significant Difference with the LSD option of the MEANS statement. An  $\alpha \leq 0.05$  was considered significantly different for all procedures. Simulated financial net return data were analyzed using StataCorp. 2011. *Stata Statistical Software: Release 12*. College Station, TX: StataCorp LP.

#### 4.3 Results and Discussion

Soybean plant population differed by soil type ( $P < 0.0001$ ), with an interaction occurring between sample date and soil type ( $P = 0.0016$ ). Moreland clay averaged 22,947 more plants ha<sup>-1</sup> than CSL across two years, however, this did not correlate to higher grain yield. Interestingly, the MCI soil consistently had higher plant populations than CSL, and actually increased from 2017 to 2018, where CSL's plant population decreased (Appendix). LSU AgCenter (2018) recommendations for optimum soybean plant populations are 192,660-256,880 plants ha<sup>-1</sup>, which shows that the CSL had less than the recommended population in 2018 at 182,042 plants ha<sup>-1</sup>. Cover crop seeding rate had no effect on soybean plant populations for either soil type for this study ( $P=0.7397$ ).

Soybean plant heights differed for sample date ( $P<0.0001$ ) and soil type ( $P= 0.0185$ ). Heights decreased from 101.6 cm in the fall of 2017 to 88.4 cm in 2018, a 13% reduction. Even though MCI had greater plant populations than CSL, plant heights were significantly greater for

CSL than MCI (97 cm and 93 cm, respectively). Cover crop seeding rate had no effect on plant heights ( $P=0.4321$ ) and no interactions occurred between other variables.

Integrating cover crops into a production system may positively impact soil health but may not consistently increase crop growth and yield. Results indicated that there were differences in grain yield for sample date ( $P < 0.0001$ ) and soil type ( $P < 0.0001$ ). Soybean yield decreased by 39% across all soil types in 2018 (Figure 4.2). Coughatta silt loam yield averaged 1,418 kg ha<sup>-1</sup> compared to 844 kg ha<sup>-1</sup> for MCI soil across two years. Soybean yield was also impacted by an interaction between sample date and soil type for soybean yield, with FALL2017 yielding 3,793 kg ha<sup>-1</sup> and FALL2018 yielding 3,215 kg ha<sup>-1</sup> for CSL soils. Moreland clay soybean yields were 65% higher in FALL2017 versus FALL2018. This could be partially attributed to high rainfall accumulation during the last 60 days prior to harvest in 2018 versus 2017 (totals of 18.3 cm and 5.5 cm, respectively) and late-season disease pressure in MCI plots (Figure 4.3).

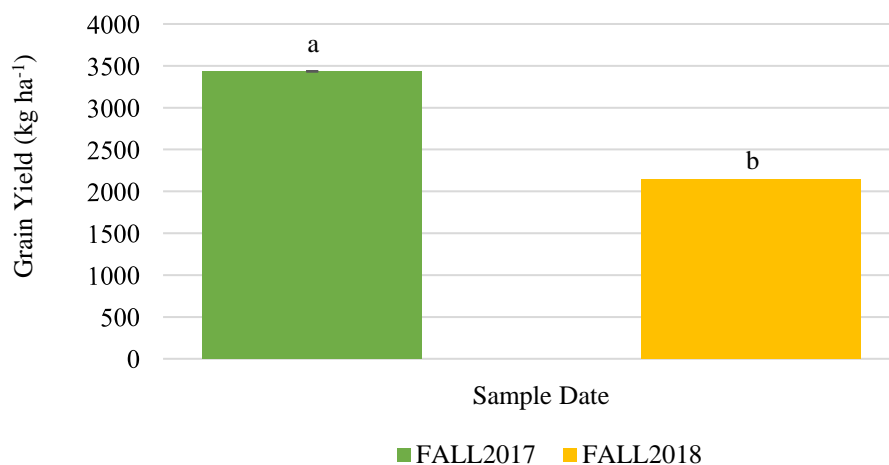


Figure 4.2. Soybean grain yield across sample dates. Bars with different superscripts are significantly different ( $\alpha=0.05$ ).



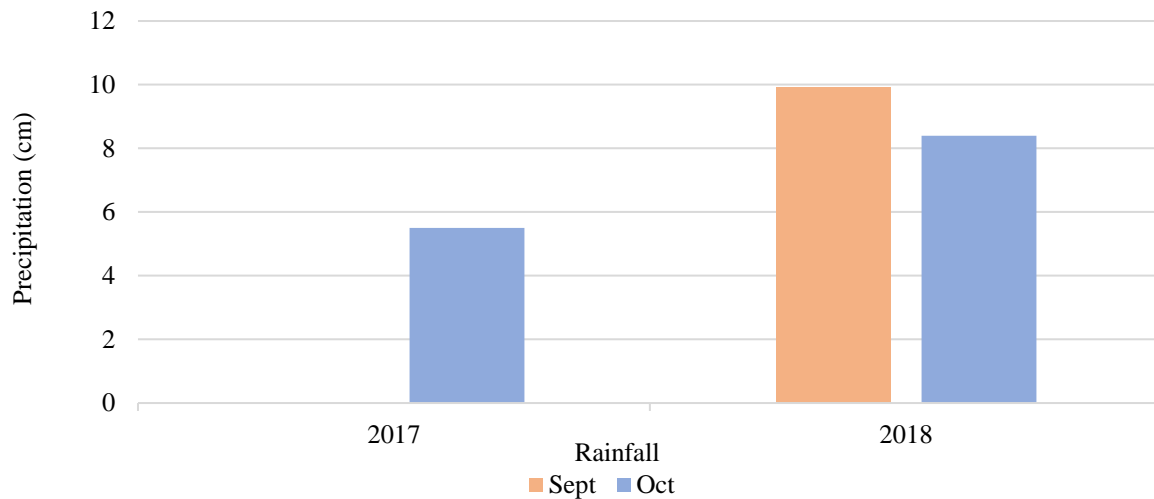


Figure 4.3. Precipitation for the last 60 days prior to soybean harvest in 2017 and 2018

Although other research has reported significant increases in corn and soybean yields following radishes compared to fallow or other cover crops (Gruver et al., 2016), cover crop species and seeding rate had no impact on soybean yield in this study across both soil types ( $P=0.739$ ). Other studies have concluded cover crops like cereal rye did not significantly positively or negatively impact soybean yields after corn (Sawyer et al., 2017), which may indicate yield differences were due to environmental and other conditions. Even though some research has shown up to 11.6% yield increase for soybeans following cover crops (Myers et al., 2019), the data did not provide consistent results of increased yields.

#### 4.3.1. Potential Economic Impacts and Estimated Net Returns

Net returns on investments are a major factor in cover crop implementation. All cover crop species used in this study were evaluated based on costs of implementation (LSU AgCenter, 2018), along with soybean grain yield for each soil type, to determine maximum potential economic profitability. The potential return on investments for the CSL soil ranged from \$204-

\$383 ha<sup>-1</sup> and \$163-\$273 ha<sup>-1</sup> for MCI, with all seeding rates compared to a standard winter-fallow treatment (only burndown herbicide costs incurred). Results indicated that in CSL soils, RYEL, RYEM, RADL, and RADM were equally profitable compared to FALL (Figure 4.4). Crimson clover was equally profitable among seeding rates (ranging from \$290 - \$304 ha<sup>-1</sup>) but all net returns were less than the FALL (\$359 ha<sup>-1</sup>). On the other hand, CCL in MCI soil were more profitable than FALL, however, RYEL was the least profitable (Figure 4.5).

Reddy (2001) reported that when evaluating winter cover crops in no-till (NT) and convention tillage (CT) systems for soybeans, it was determined that net return on investment was highest in both fallow treatments, NT at \$105 ha<sup>-1</sup>, followed by CT at \$76 ha<sup>-1</sup>, with negative net returns for all cover crop species. Results from this study estimated financial net return for FALL treatment in MCI soil was \$231.81 ha<sup>-1</sup>, which was 35% lower than CSL soil at \$358.55 ha<sup>-1</sup>, but still higher than some reported research results. When cover crop treatments were equally profitable to FALL, this would indicate the cover crop “paid for itself”, while likely providing intangible benefits described earlier. Because CSL soybean yields were significantly higher than MCI yields for this study both years, the majority of higher net returns were correlated to CSL soil type as well.

Jiang and Thelen (2004) found that when comparing yield-limiting soil properties in corn and soybean cropping systems, soil variables such as base saturation, pH, clay content, and elevation were helpful in explaining yield variability, which may explain yield differences, and ultimately net returns, in this study. Other research has indicated that performance of production systems in terms of crop yields and net returns is influenced by location and production year, with conventional and fallow systems having higher net returns than no-till systems (Popp et al., 2002). Fallow treatments in this study did provide substantial financial net returns for both soil

types, however, may not account for any potential soil health improvements or other benefits from cover crop implementation.

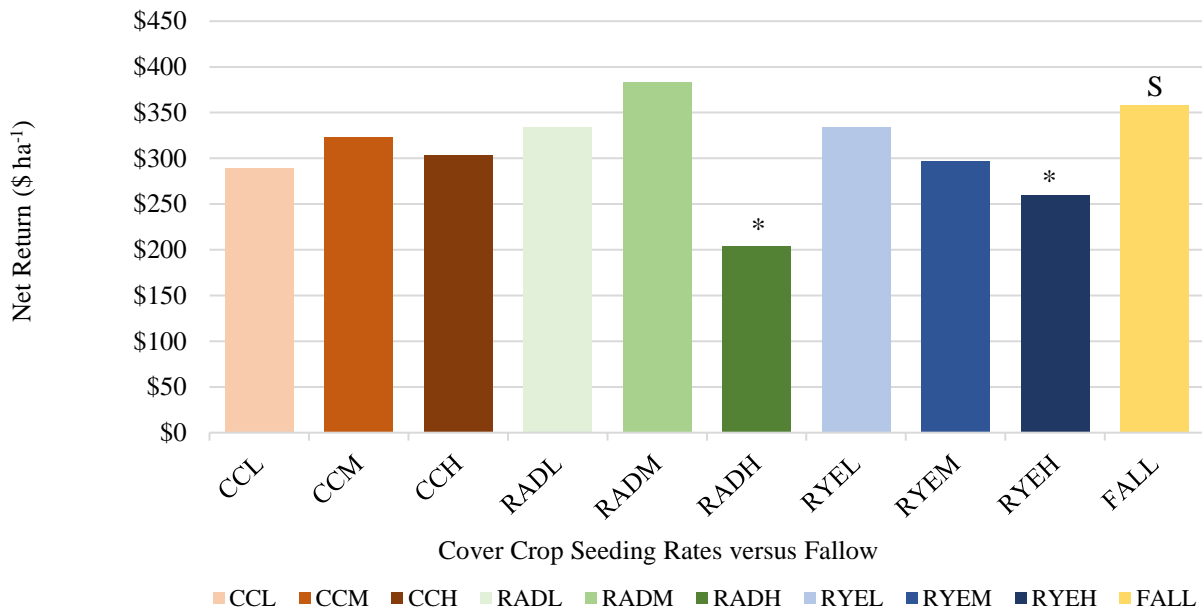


Figure 4.4. Simulated net returns for cover crop seeding rates in Coughatta silt loam soil compared to fallow treatment. Bars with asterisks are significantly different ( $\alpha=0.05$ ) from the farmer standard treatment (S).

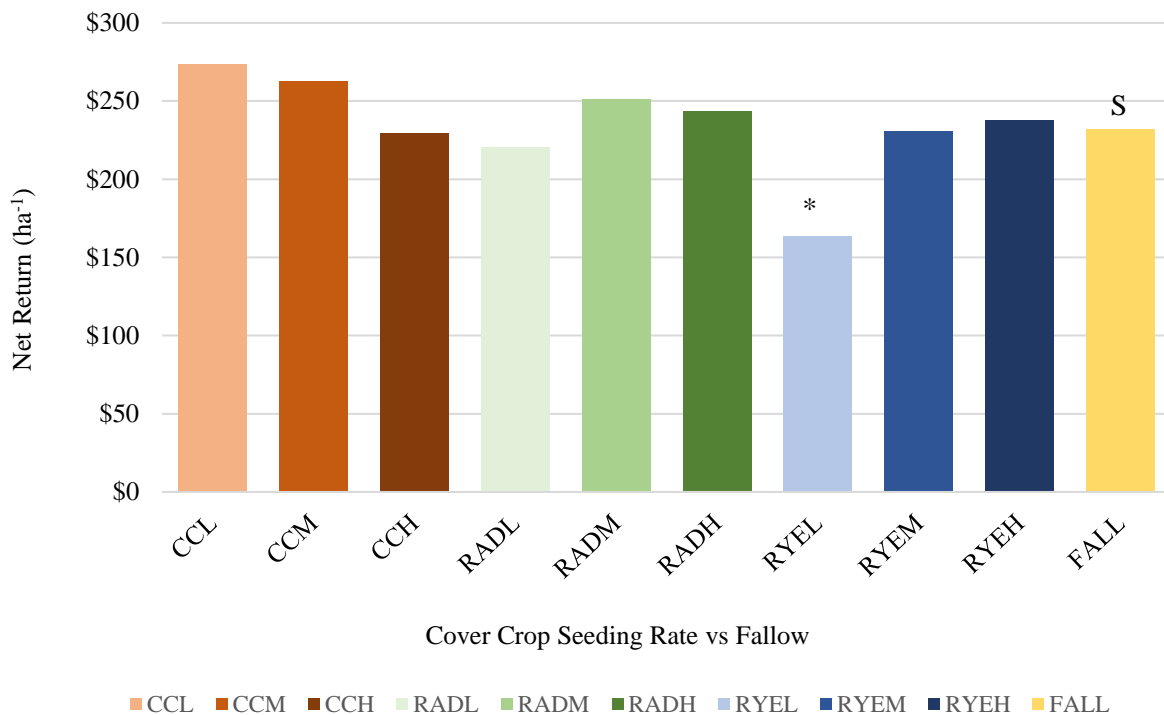


Figure 4.5. Simulated net returns for cover crop seeding rates in Moreland clay soil compared to fallow treatment. Bars with asterisk are significantly different ( $\alpha=0.05$ ) than the farmer standard treatment (S).

#### 4.4 Conclusion

Soil type affected soybean plant population, soybean plant heights, and soybean grain yield in this study, however, cover crop seeding rate did not. Differences in plant population indicated MCI soil consistently had higher populations than CSL for both growing seasons, but that did not correlate to higher grain yields. Wet field conditions at planting may have impacted emergence in 2017, with drought conditions in 2018 also affecting emergence and ultimately plant population in CSL. Plant heights were greater in CSL plots than MCI, but there were no differences in cover crop seeding rate, which suggests that cover crop residue may have provided early season N to the soybeans for additional plant growth. Yearly variations in environmental conditions also impacted yield for sample dates across years, with a significant reduction in yield

for 2018. Lower seeding rates of all cover crop species had no negative impact on soybean yield versus fallow, with those seeding rates being equally profitable compared to fallow. Other benefits provided by cover crops such as reduced erosion, N fixation and scavenging, and improved soil health at lower seeding rates may help producers manage their input costs and provide incentives while still maintaining cash crop yields and positive net returns.

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## CHAPTER 5. CONCLUSIONS

The objectives of this study were to evaluate the impact of seeding rates and soil type on cover crop biomass, weed suppression, soil fertility, soybean growth, and soybean yield. Cover crop biomass from tillage radish was influenced by seeding rate more than cereal rye and crimson clover, with low and medium rates resulting in greater biomass than high seeding rates. Crimson clover produced the least biomass and weed populations were greatest in that species compared with all other treatments. The cereal rye and tillage radish treatments produced the least weed biomass, suggesting these species may be excellent for weed suppression in cash crops. Findings indicate that not only species, but seeding rate within species, may affect cover crop biomass and subsequent weed suppression, however soil type did not affect cover crop biomass for these three species.

Soil nutrients, including inorganic N, fluctuated with sampling date, but all decreased by the end of the study. Inherent differences in clay and silt loam soil types also played a role in subsequent soil nutrient levels. The low seeding rate of tillage radish not only produced the greatest cover crop biomass, it also contributed the highest total N per hectare. This finding suggests that if increased N is required for a subsequent cash crop, this species may be of interest for future investigations, while keeping in mind C:N ratios for tillage radish may limit available N in the short-term. While soil organic matter levels fluctuated, it was not increased during the course of this study for either soil type. Even though cover crop seeding rate exhibited an effect on soybean growth, this increase in growth did not manifest itself in increased grain yield. Soybean grain yield was higher in silt loam soils compared with clay across both years but was not impacted by high or low seeding rates of cover crops. Excessive fluctuations in environmental conditions affected both the cover crop growth and soybean yields in the second

year, which indicate that weather conditions at critical times throughout the production cycle probably have the largest effect on yield compared with other variables evaluated in this study. Low to medium cover crop seeding rates of tillage radish and cereal rye can provide equal or greater financial net returns compared with higher seeding rates in Coushatta silt loam soils, while low seeding rates of cereal rye resulted in the lowest net return for Moreland clay soil. This suggests that economic net returns are not only species and seeding rate specific but can be affected by soil type. Additional research, across multiple environmental conditions and cropping systems, needs to be conducted to address variability from year to year.



## APPENDIX: SUPPLEMENTAL DATA

Table A1. Interaction of sample date by soil type for soil organic matter ( $P<0.0001$ ). Standard errors are in parenthesis.

Soil Type†	Sample Date				
	%				
	FALL2016	SPR2017	FALL2017	SPR2018	FALL2018
CSL	1.82(0.04) a‡	1.14(0.03) c	1.60 (0.03) b	1.40 (0.03) c	1.39 (0.03) c
MCI	3.21(0.06) a	2.84(0.05) b	2.88(0.05) b	2.47(0.07) c	2.43(0.07) c

†CSL - Coughatta silt loam; MCI - Moreland clay

‡Lowercase letters denote differences in organic matter across sample dates

Table A2. Interaction of cover crop seeding rate and soil type for soil organic matter. Standard errors are in parenthesis.

Cover Crop & Seeding Rate†	Soil Type	
	Coughatta silt loam	Moreland clay
	%	
CCL	1.61 (0.07) ab‡	2.90 (0.12) a
CCM	1.41 (0.05) cd	2.64 (0.11) cd
CCH	1.56 (0.05) abcd	2.70 (0.11) bc
RADL	1.51 (0.07) abcd	2.86 (0.09) ab
RADM	1.56 (0.06) abcd	2.48 (0.12) d
RADH	1.40 (0.04) d	2.81 (0.11) abc
RYEL	1.63 (0.06) a	2.85 (0.12) ab
RYEM	1.43 (0.05) bcd	2.76 (0.08) abc
RYEH	1.59 (0.09) abc	2.92 (0.11) a
FALL	1.58 (0.05) abcd	2.74 (0.13) abc
<i>P value</i>	<i>&lt;0.0001</i>	<i>0.0130</i>

†CC – crimson clover; RAD – tillage radish; RYE – cereal rye; FALL – fallow; L – low seeding rate; M – medium seeding rate; H – high seeding rate

‡Lowercase letters denotes differences in percent soil organic matter across cover crop seeding rates within each soil type

Table A3. Interaction of sample date by soil type for percent cover crop biomass carbon concentration ( $\alpha=0.05$ ). Standard errors are in parenthesis.

Soil Type†	Sample Date	
	SPR2017	SPR2018
	%	
CSL	31.1(4.16)a‡	40.1(4.83)b
MCI	39.4(3.51)a	22.5(3.48)b

†CSL – Coughatta silt loam; MCI – Moreland clay

‡Lowercase letters denote differences in cover crop biomass carbon across sample dates

Table A4. Three-way interaction of cover crop biomass carbon concentration for sample date by soil type by cover crop seeding rate. Standard errors are in parenthesis.

Cover Crop & Seeding Rate†	SPR2017	SPR2018	SPR2017	SPR2018
	Coushatta silt loam		Moreland clay	
	%			
CCL	37.9(1.5)bc‡	37.6(4.2)b	39.3(0.7)abcd	12.4(0)ef
CCM	25.0(12.5)bcd	10.7(0.9)cd	26.4(13.1)de	26.7(0.9)de
CCH	25.3(0.75)b	41.9(1.1)b	39.4(1.2)abcd	37.8(2.5)bcd
RADL	44.4(2.1)b	74.0(3.7)a	63.5(2.3)a	10.1(0)ef
RADM	40.2(8.0)b	69.7(1.4)a	60.4(1.6)ab	12.0(0)ef
RADH	30.2(17.7)bc	73.8(8.9)a	52.3(7.5)abc	11.7(0)ef
RYEL	41.1(0.7)b	38.1(5.3)b	40.5(0.7)abcd	41.2(0.7)abcd
RYEM	25.4(2.9)bc	21.8(6.7)bcd	40.0(1.0)abcd	39.1(1.8)abcd
RYEH	41.8(0.2)b	37.2(1.8)b	32.0(7.9)cde	34.0(6.1)cde
<i>P value</i>	<i>&lt;0.0001</i>			

†CC – crimson clover; RAD – tillage radish; RYE – cereal rye; FALL – fallow; L – low seeding rate; M – medium seeding rate; H – high seeding rate

‡Lowercase letters denotes differences in percent soil organic matter across cover crop seeding rates

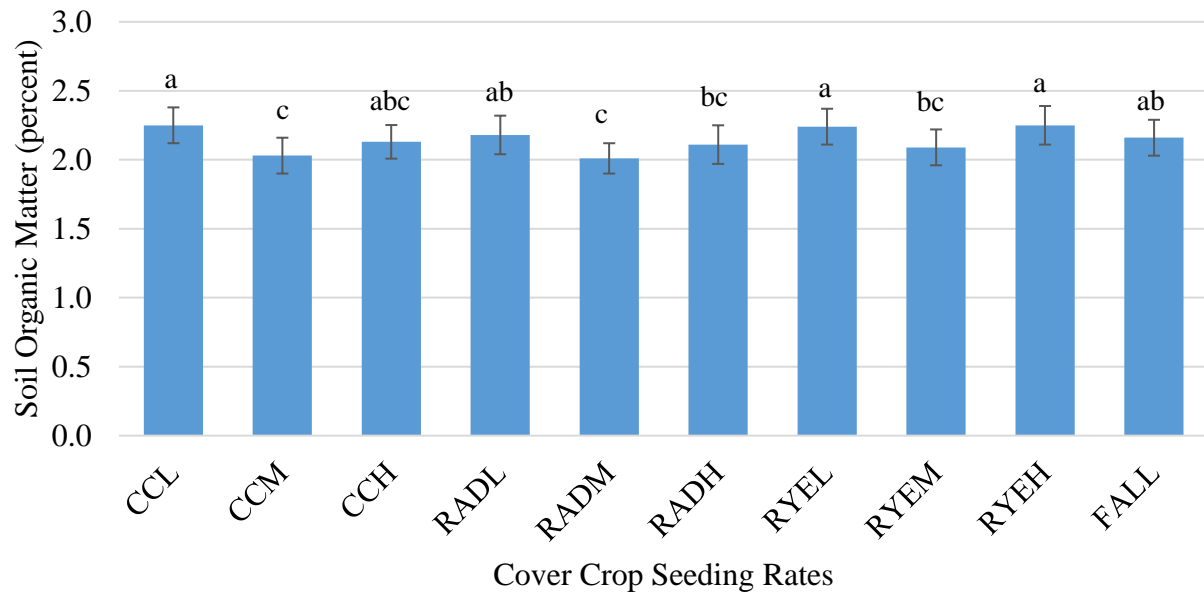


Figure A1. Percent soil organic matter for cover crop seeding rate. Bars with different superscripts are significantly different at ( $\alpha=0.05$ ).

Table A5. Interaction of sample date by cover crop seeding rate for cover crop biomass (kg ha<sup>-1</sup>). Standard errors are in parenthesis.

Sample Date	Cover Crop and Seeding Rate								
	CCL†	CCM	CCH	RADL	RADM	RADH	RYEL	RYEM	RYEH
SPR2017	861(315)cdefg‡	1435(768)bcde	2081(566)ab	2942(747)a	2081(515)ab	1184(214)bcdef	1507(289)bcd	1794(415)bc	2045(547)ab
SPR2018	287(106)fg	251(141)fg	251(66)fg	682(307)defg	646(242)defg	1184(111)efg	1650(298)bcd	861(222)cdefg	1184(265)bcdef
<i>P value</i>	0.0312								

†CC – crimson clover; RAD – tillage radish; RYE – cereal rye; FALL – fallow; L – low seeding rate; M – medium seeding rate; H – high seeding rate

‡Lowercase letters denotes differences in percent soil organic matter across cover crop seeding rates

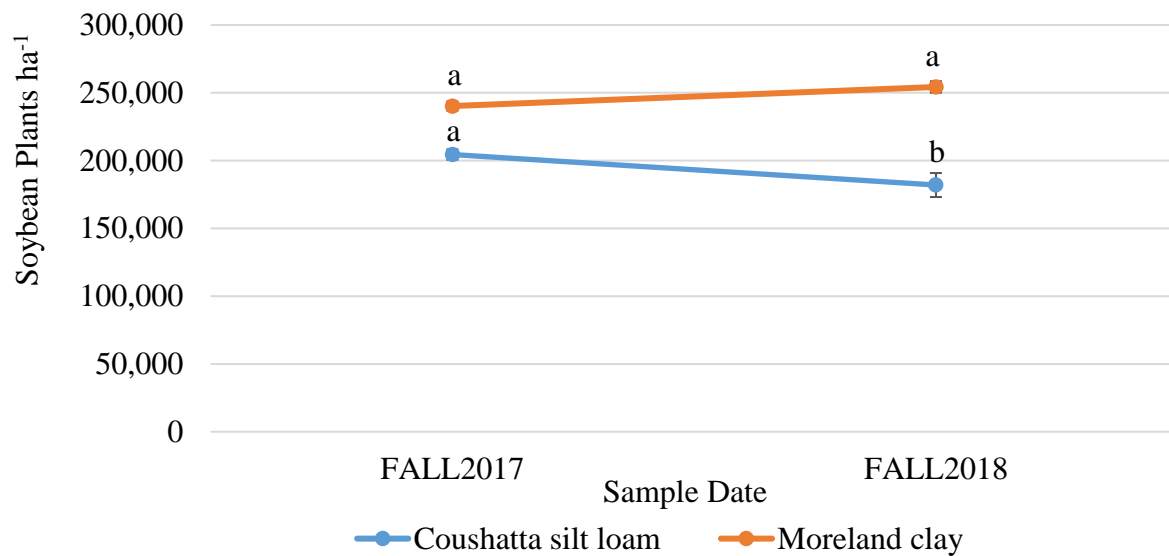


Figure A2. Interaction of soybean plant population for sample date by soil type. Bars with different superscripts are significantly different at ( $\alpha=0.05$ ).

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## **VITA**

Donna Sue Taylor Morgan was raised in Bernice, Louisiana, a small town in Union Parish, and was very involved in school agricultural activities such as FFA and 4-H. She graduated from Bernice High School in 1988 and received her B.S. in Agri-business from the University of Southwestern Louisiana in May 1996. She began her career in the agricultural industry, then moved on to the LSU AgCenter as an extension associate, then area extension agent for many years. She completed her M.S. degree in Soil, Plant, and Environmental Systems from Louisiana State University in 2014 under the direction of Dr. James “Jim” Griffin. In 2016, she was accepted into a doctoral program under the direction of Dr. Lisa Fultz, with her research focusing on cover crop seeding rates for different soil types in a soybean production system. Donna currently works as a Conservation Agronomy Extension Agent for the LSU AgCenter and lives in Clinton, Louisiana with her husband Glen Gentry. Donna is the proud mother of three children: Caitlin DeNux- 27 years old, Tyler Woodard- 26 years old, and Caleb Morgan- 17 years old.